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Koshiba et al.

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(45) **Date of Patent: Oct. 4, 2016**

(54) **PIXEL CORRECTION METHOD AND IMAGE CAPTURE DEVICE**

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(73) Assignee: **FUJIFILM Corporation**, Tokyo (JP)

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(30) **Foreign Application Priority Data**

Dec. 28, 2012 (JP) 2012-287317

(51) **Int. Cl.**

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H04N 5/369 (2011.01)
H04N 5/347 (2011.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H04N 9/045*** (2013.01); ***H01L 27/1464*** (2013.01); ***H01L 27/14603*** (2013.01); ***H01L 27/14621*** (2013.01); ***H01L 27/14623*** (2013.01); ***H04N 5/23212*** (2013.01); ***H04N 5/347*** (2013.01); ***H04N 5/35563*** (2013.01); ***H04N 5/367*** (2013.01); ***H04N 5/369*** (2013.01);

(Continued)

(58) **Field of Classification Search**

None

See application file for complete search history.

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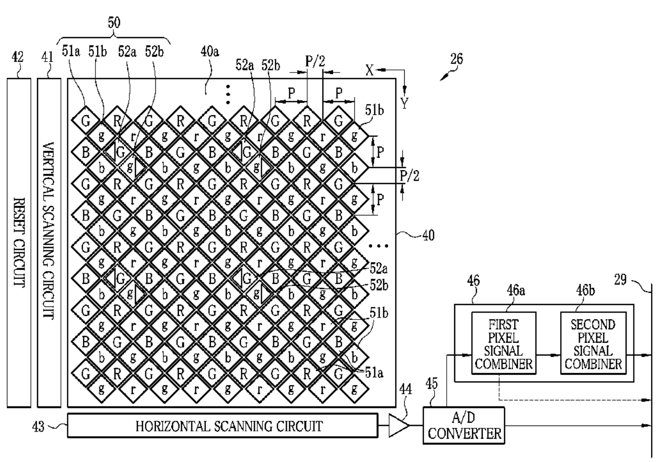
(57) **ABSTRACT**

A color image sensor comprises normal pixels and phase difference pixels. A pixel combining circuit combines pixel signals of the normal pixels, and combines pixel signals of the normal pixel and the phase difference pixel of the same color. Thereby the pixel combining circuit produces a composite image. An edge detector uses a pixel signal of each pixel in the composite image to detect an edge of a subject. The edge is vertical to a direction in which a difference between the pixel signals is at the maximum. A pixel signal correction processor corrects the combined pixel signals through interpolation along the edge and with the use of pixel signals of the same color obtained by combining the pixel signals of the normal pixels in a case where the pixel signals of the phase difference pixels are combined across the edge.

11 Claims, 16 Drawing Sheets



(51) **Int. Cl.**

H04N 5/355	(2011.01)
H04N 5/367	(2011.01)
H04N 5/232	(2006.01)
H04N 9/07	(2006.01)
H01L 27/146	(2006.01)
H04N 9/04	(2006.01)

(52) **U.S. Cl.**
CPC ***H04N5/3696*** (2013.01); ***H04N 9/07*** (2013.01); *H04N 2209/046* (2013.01)

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FIG. 1

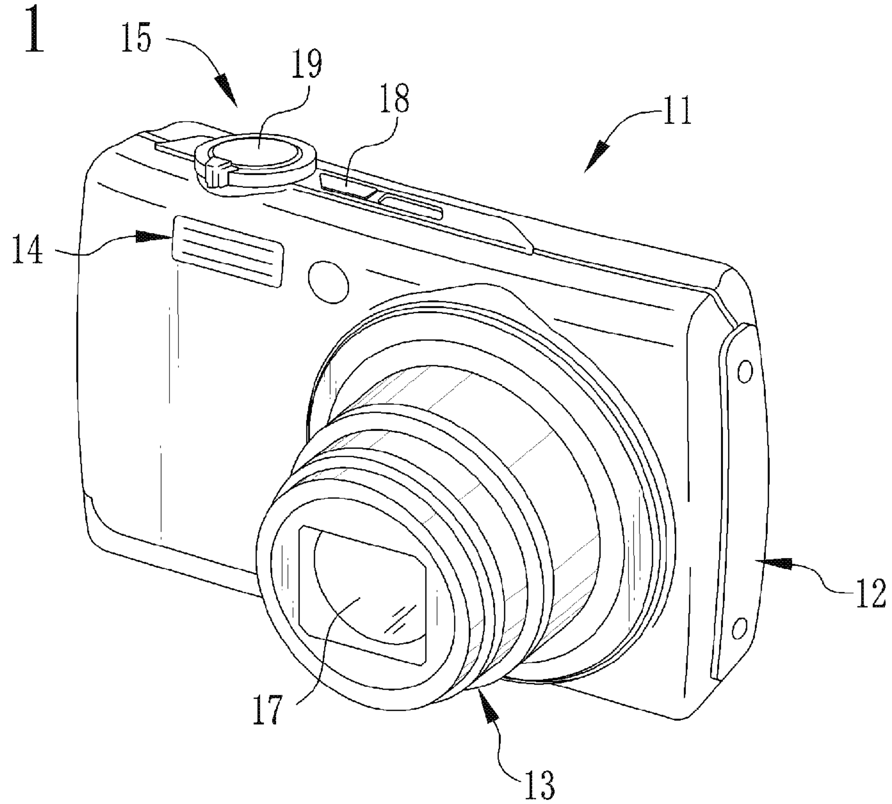


FIG. 2

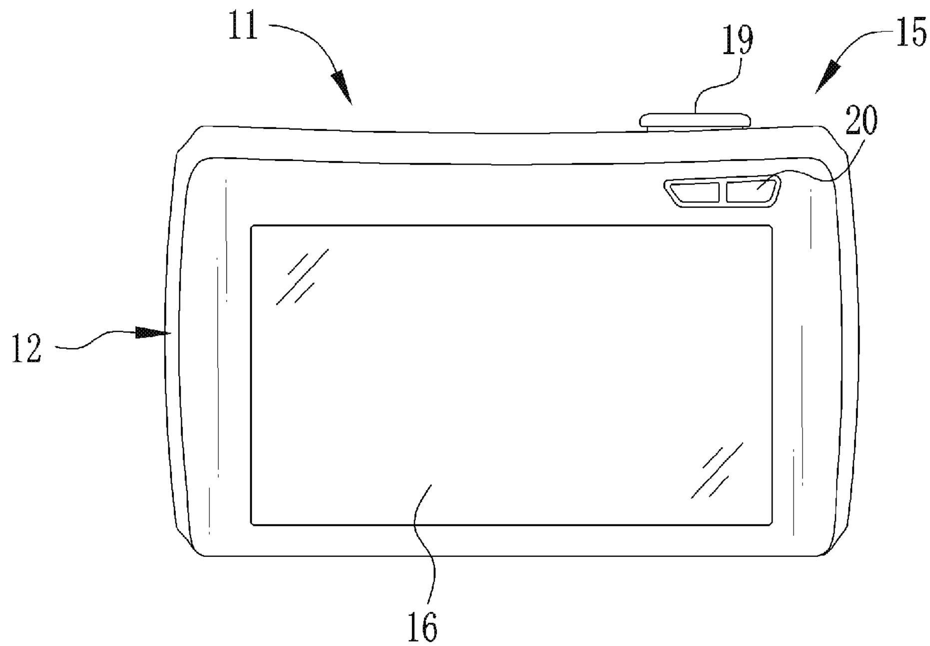


FIG. 3

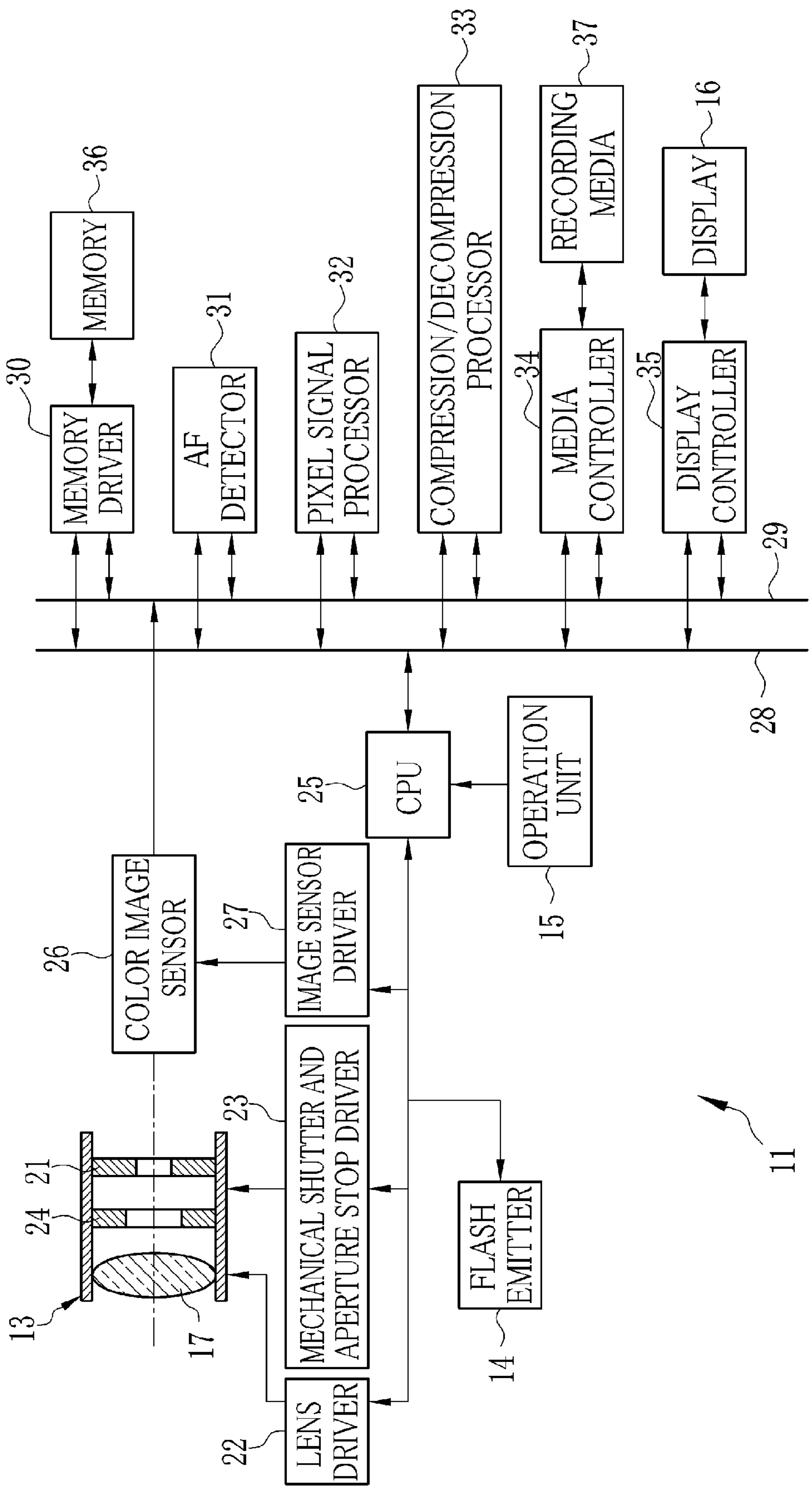
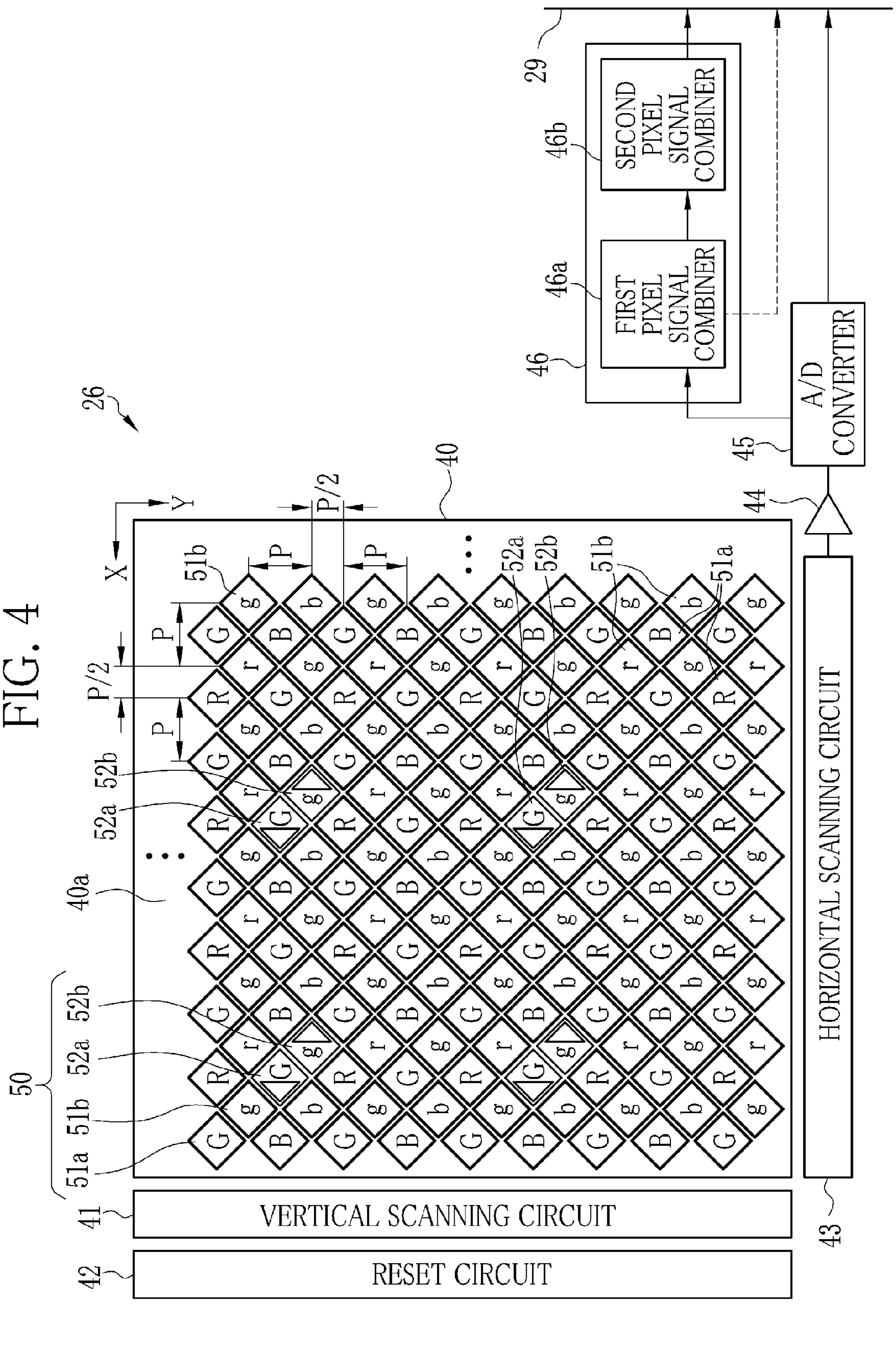

MEMORY
36
MEMORY DRIVER
30
AF DETECTOR
31
PIXEL SIGNAL PROCESSOR
32
COMPRESSION/DECOMPRESSION PROCESSOR
33
RECORDING MEDIA
37
MEDIA CONTROLLER
34
DISPLAY
16
DISPLAY CONTROLLER
35
29
28
CPU
25
OPERATION UNIT
15
COLOR IMAGE SENSOR
26
IMAGE SENSOR DRIVER
27
MECHANICAL SHUTTER AND APERTURE STOP DRIVER
23
FLASH EMITTER
14
LENS DRIVER
22
13
17
21
24
11

FIG. 4



VERTICAL SCANNING CIRCUIT
RESET CIRCUIT
HORIZONTAL SCANNING CIRCUIT
A/D CONVERTER
FIRST PIXEL SIGNAL COMBINER
SECOND PIXEL SIGNAL COMBINER

FIG. 5

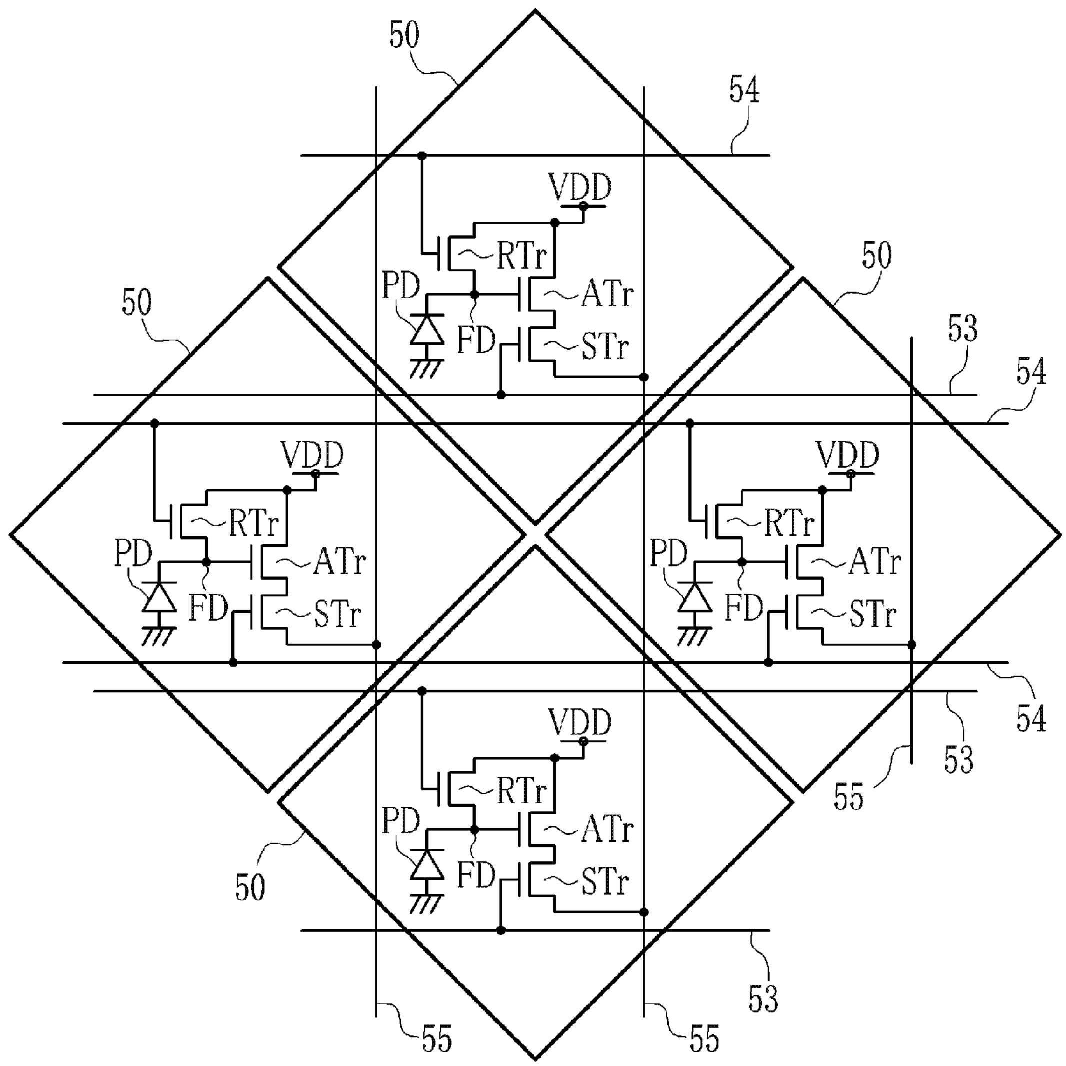

50
54
VDD
RTr
PD
ATr
FD
STr
50
53
54
50
VDD
RTr
PD
ATr
FD
STr
VDD
RTr
PD
ATr
FD
STr
54
53
VDD
55
53
RTr
PD
ATr
FD
STr
50
53
55
55

FIG. 6

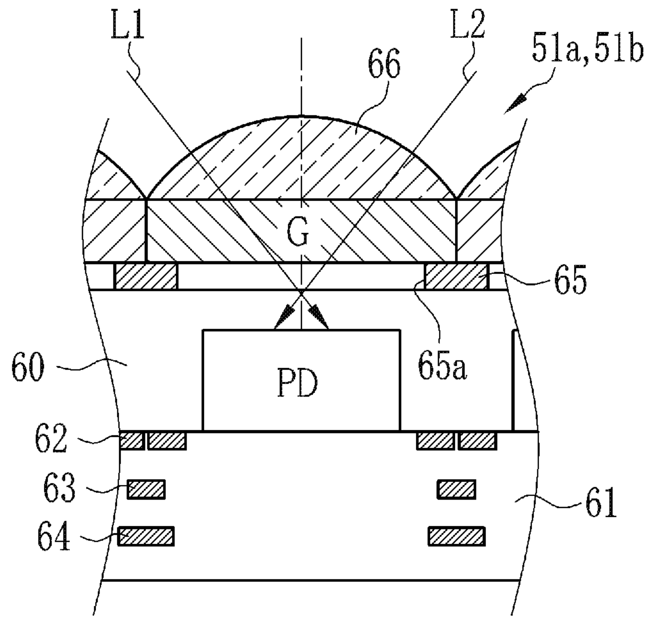

L1
L2
66
51a,51b
G
65
65a
60
PD
62
63
61
64

FIG. 7

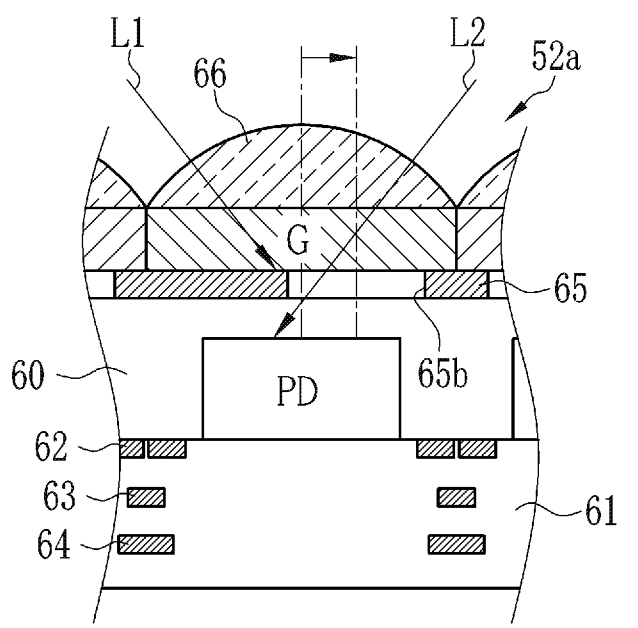

L1
L2
66
52a
G
65
65b
60
PD
62
63
61
64

FIG. 8

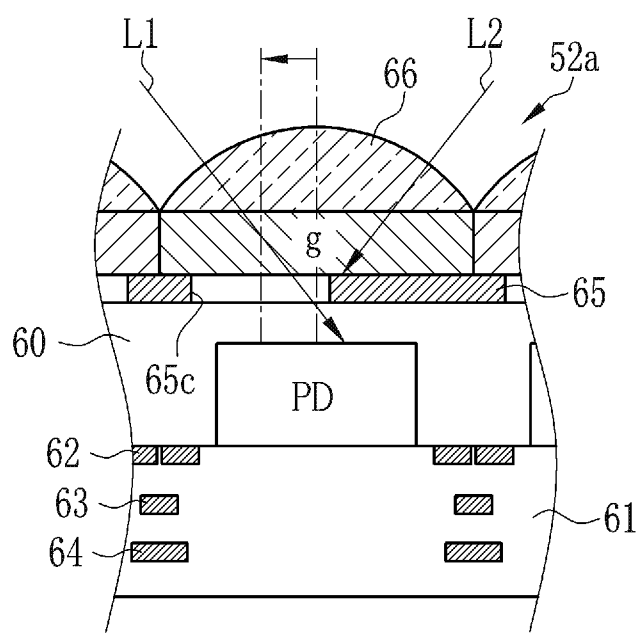


FIG. 9

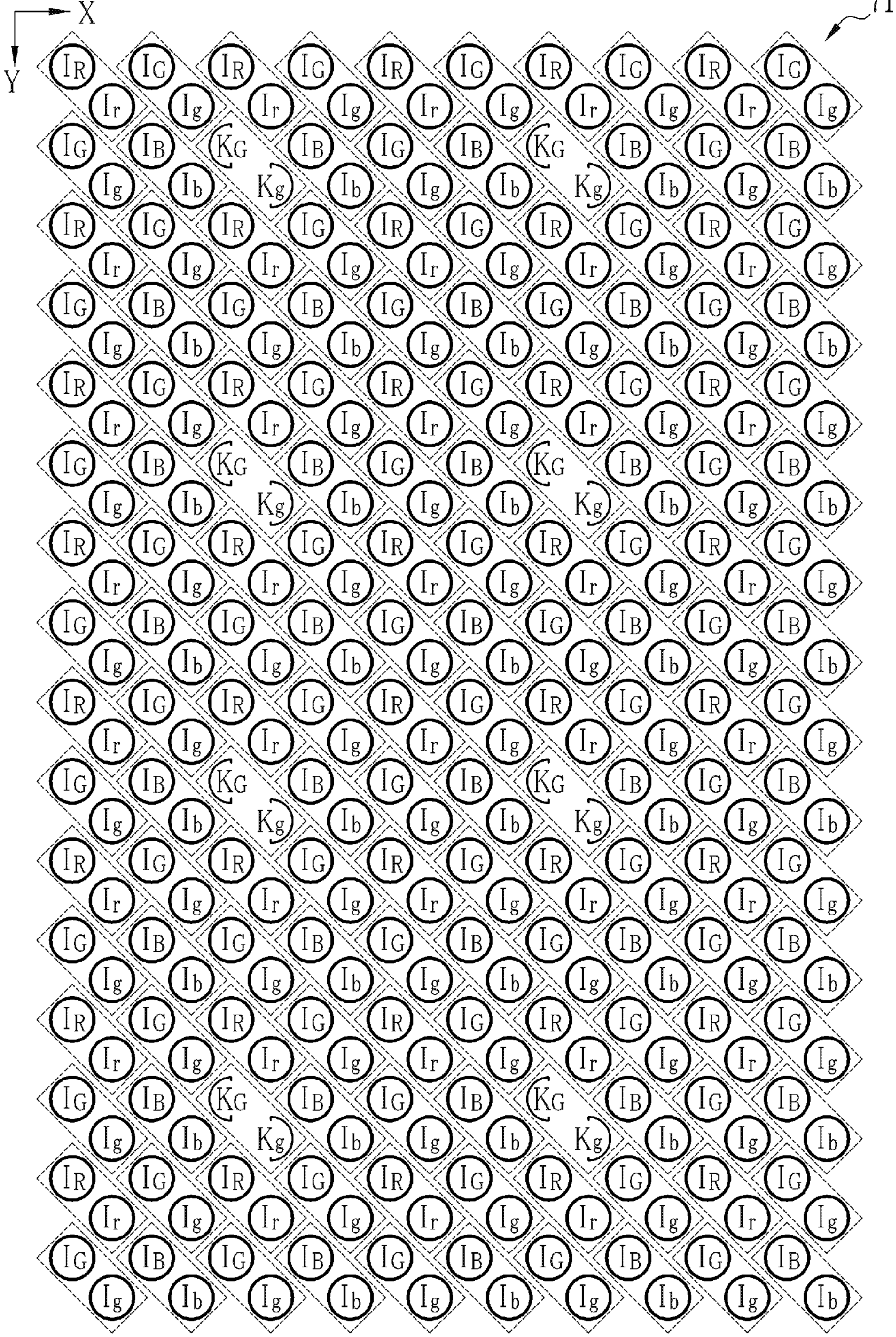


FIG. 10

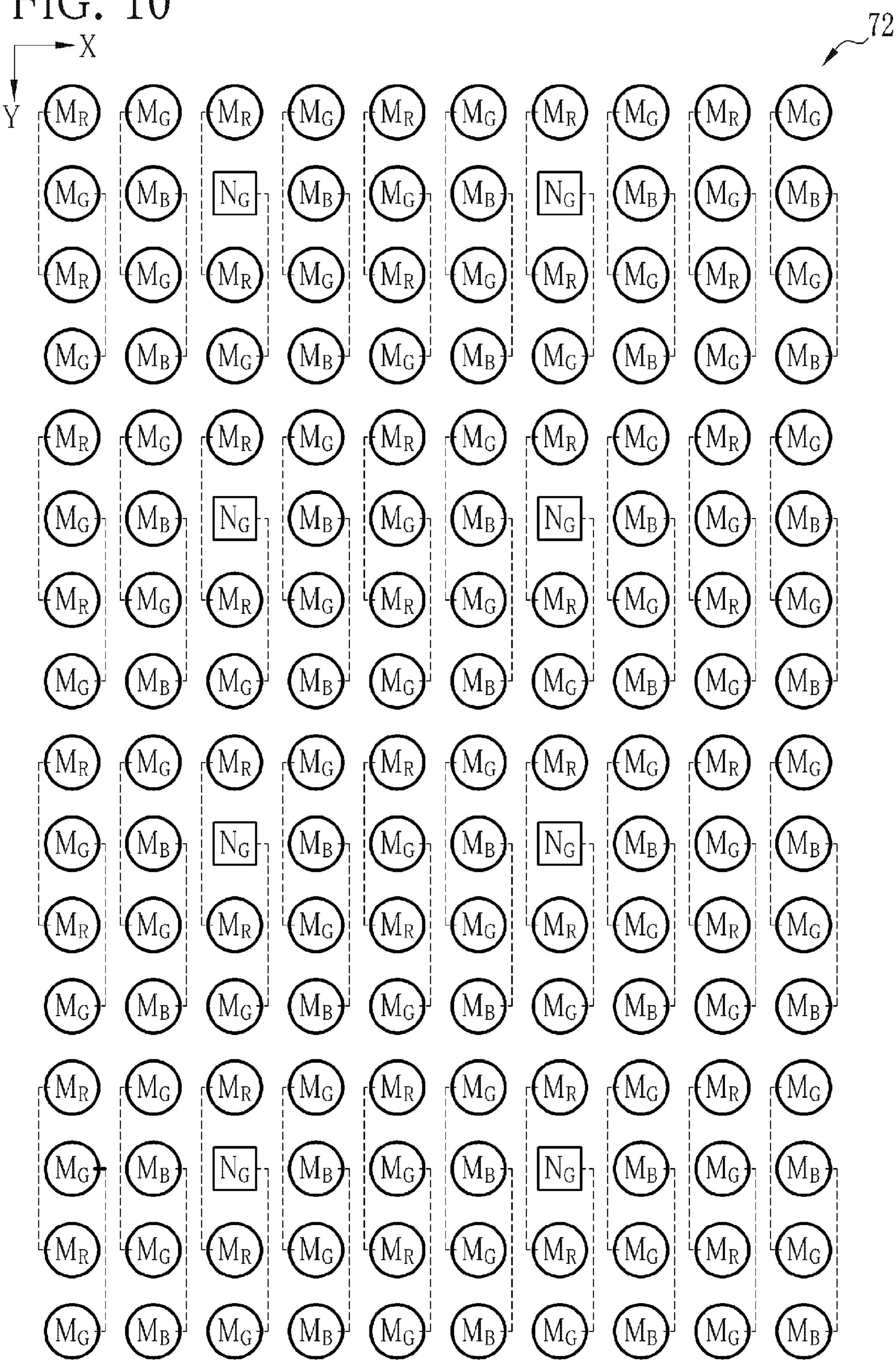

72
X
Y
M_R M_G M_R M_G M_R M_G M_R M_G M_R M_G
M_G M_B N_G M_B M_G M_B N_G M_B M_G M_B
M_R M_G M_R M_G M_R M_G M_R M_G M_R M_G
M_G M_B M_G M_B M_G M_B M_G M_B M_G M_B
M_R M_G M_R M_G M_R M_G M_R M_G M_R M_G
M_G M_B N_G M_B M_G M_B N_G M_B M_G M_B
M_R M_G M_R M_G M_R M_G M_R M_G M_R M_G
M_G M_B M_G M_B M_G M_B M_G M_B M_G M_B
M_R M_G M_R M_G M_R M_G M_R M_G M_R M_G
M_G M_B N_G M_B M_G M_B N_G M_B M_G M_B
M_R M_G M_R M_G M_R M_G M_R M_G M_R M_G
M_G M_B M_G M_B M_G M_B M_G M_B M_G M_B
M_R M_G M_R M_G M_R M_G M_R M_G M_R M_G
M_G M_B N_G M_B M_G M_B N_G M_B M_G M_B
M_R M_G M_R M_G M_R M_G M_R M_G M_R M_G
M_G M_B M_G M_B M_G M_B M_G M_B M_G M_B

FIG. 11

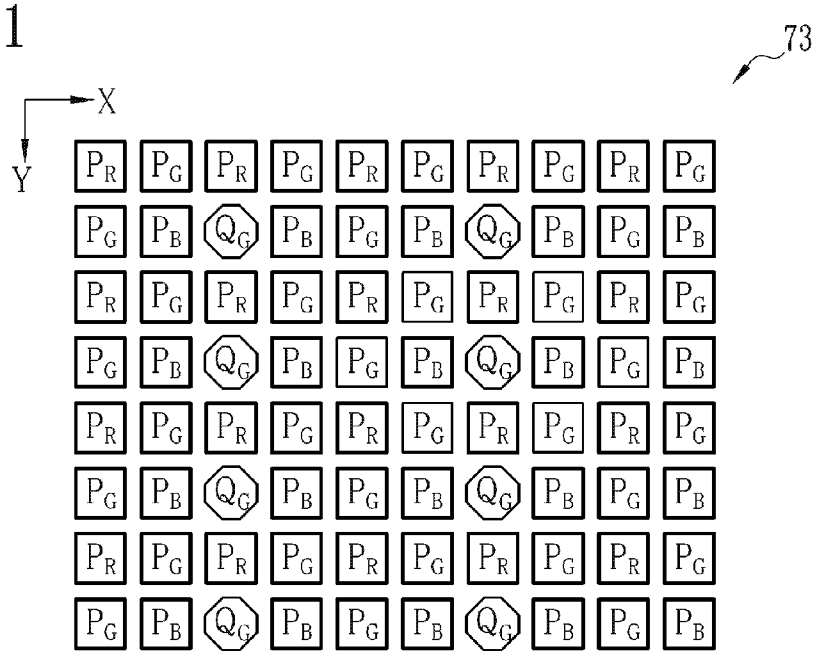

73
X
Y
P_R P_G P_R P_G P_R P_G P_R P_G P_R P_G
P_G P_B Q_G P_B P_G P_B Q_G P_B P_G P_B
P_R P_G P_R P_G P_R P_G P_R P_G P_R P_G
P_G P_B Q_G P_B P_G P_B Q_G P_B P_G P_B
P_R P_G P_R P_G P_R P_G P_R P_G P_R P_G
P_G P_B Q_G P_B P_G P_B Q_G P_B P_G P_B
P_R P_G P_R P_G P_R P_G P_R P_G P_R P_G
P_G P_B Q_G P_B P_G P_B Q_G P_B P_G P_B

FIG. 12

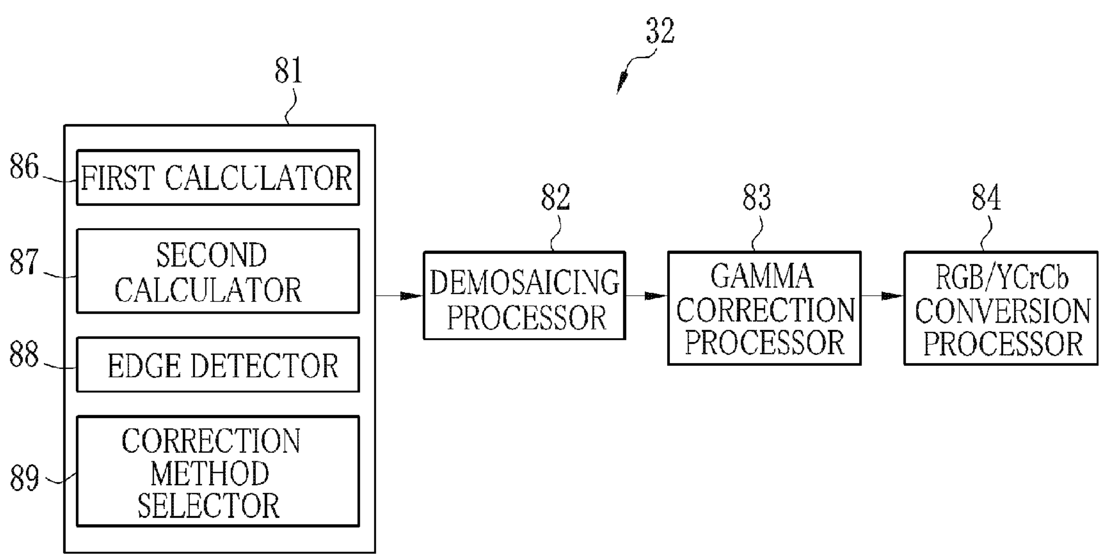

32
81
86
FIRST CALCULATOR
87
SECOND CALCULATOR
88
EDGE DETECTOR
89
CORRECTION METHOD SELECTOR
82
DEMOSAICING PROCESSOR
83
GAMMA CORRECTION PROCESSOR
84
RGB/YCrCb CONVERSION PROCESSOR

FIG. 13

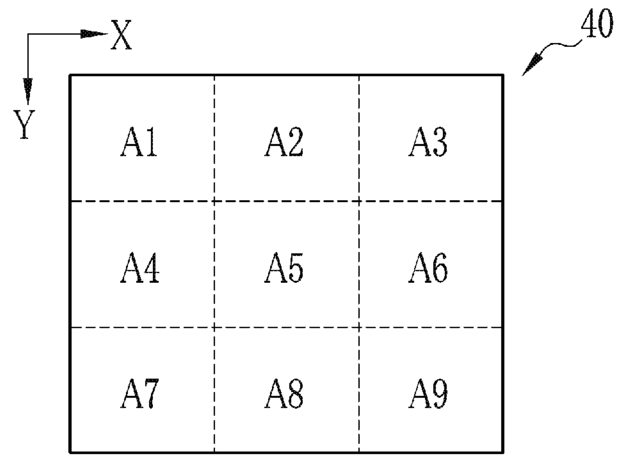

X
Y
40
A1
A2
A3
A4
A5
A6
A7
A8
A9

FIG. 14

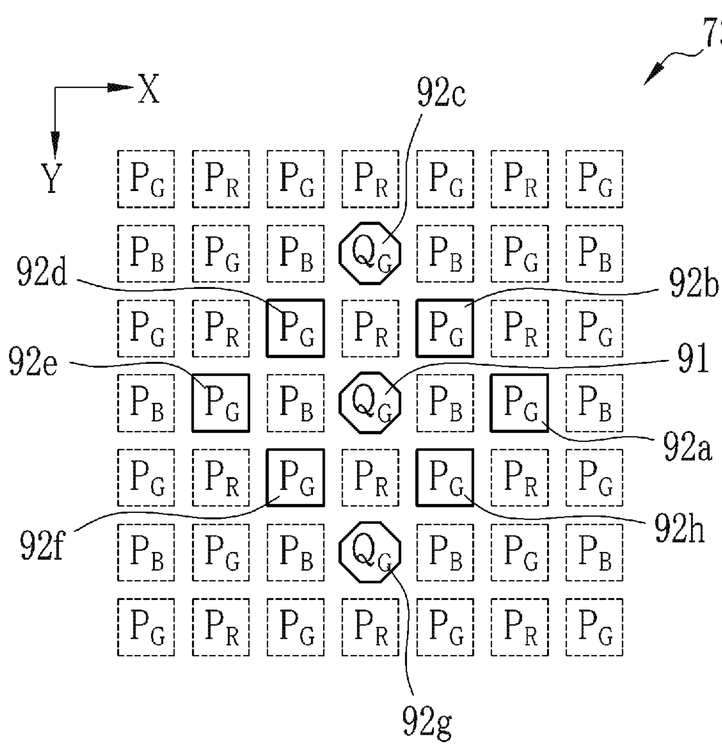

73
X
Y
92c
92d
92b
92e
91
92a
92f
92h
92g

FIG. 15

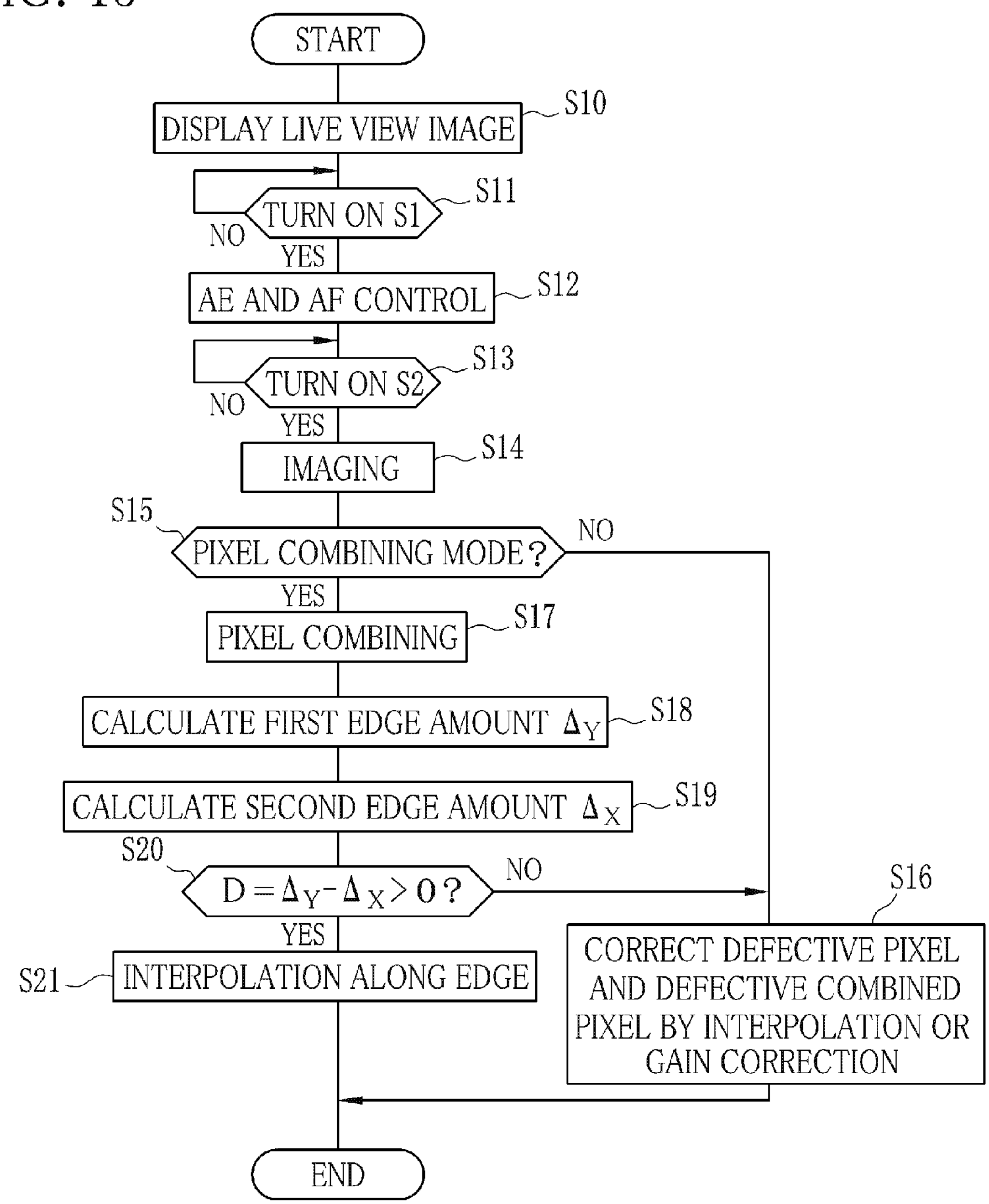

START
DISPLAY LIVE VIEW IMAGE
S10
TURN ON S1
S11
NO
YES
AE AND AF CONTROL
S12
TURN ON S2
S13
NO
YES
IMAGING
S14
S15
PIXEL COMBINING MODE?
NO
YES
PIXEL COMBINING
S17
CALCULATE FIRST EDGE AMOUNT Δ_Y
S18
CALCULATE SECOND EDGE AMOUNT Δ_X
S19
S20
$D = \Delta_Y - \Delta_X > 0$?
NO
S16
YES
S21
INTERPOLATION ALONG EDGE
CORRECT DEFECTIVE PIXEL AND DEFECTIVE COMBINED PIXEL BY INTERPOLATION OR GAIN CORRECTION
END

FIG. 16

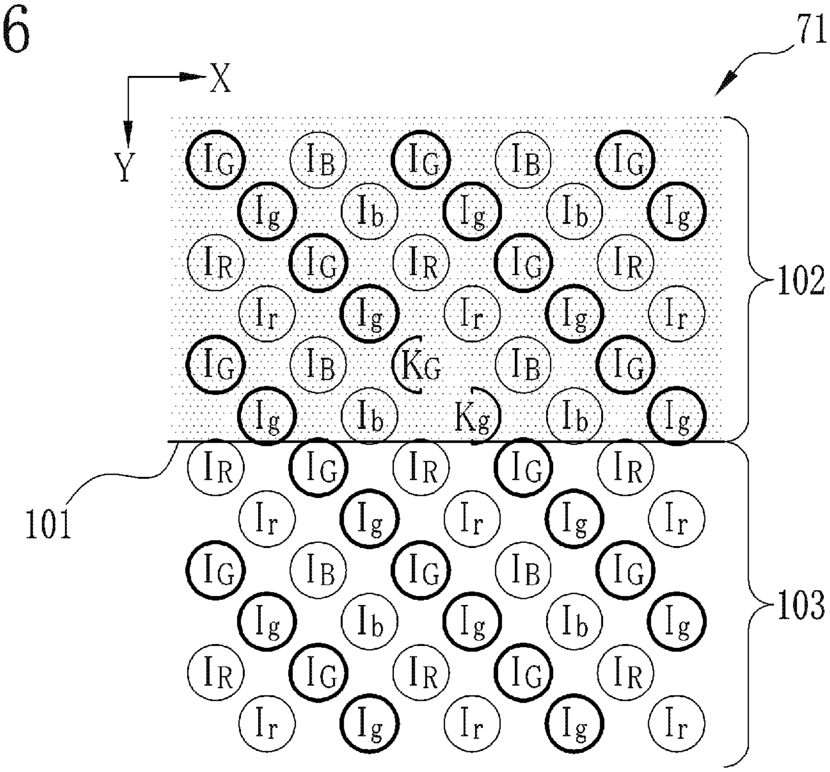

71
X
Y
I_G I_B I_G I_B I_G
I_g I_b I_g I_b I_g
I_R I_G I_R I_G I_R
I_r I_g I_r I_g I_r
I_G I_B K_G I_B I_G
I_g I_b K_g I_b I_g
I_R I_G I_R I_G I_R
I_r I_g I_r I_g I_r
I_G I_B I_G I_B I_G
I_g I_b I_g I_b I_g
I_R I_G I_R I_G I_R
I_r I_g I_r I_g I_r
102
101
103

FIG. 17

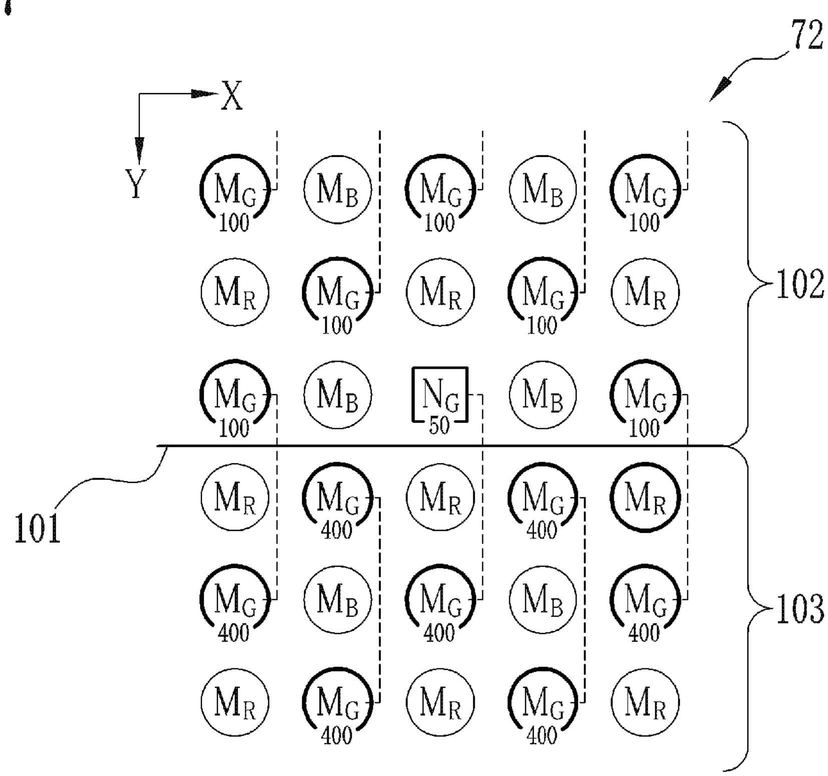

72
X
Y
M_G 100 M_B M_G 100 M_B M_G 100
M_R M_G 100 M_R M_G 100 M_R
M_G 100 M_B N_G 50 M_B M_G 100
M_R M_G 400 M_R M_G 400 M_R
M_G 400 M_B M_G 400 M_B M_G 400
M_R M_G 400 M_R M_G 400 M_R
102
101
103

FIG. 18

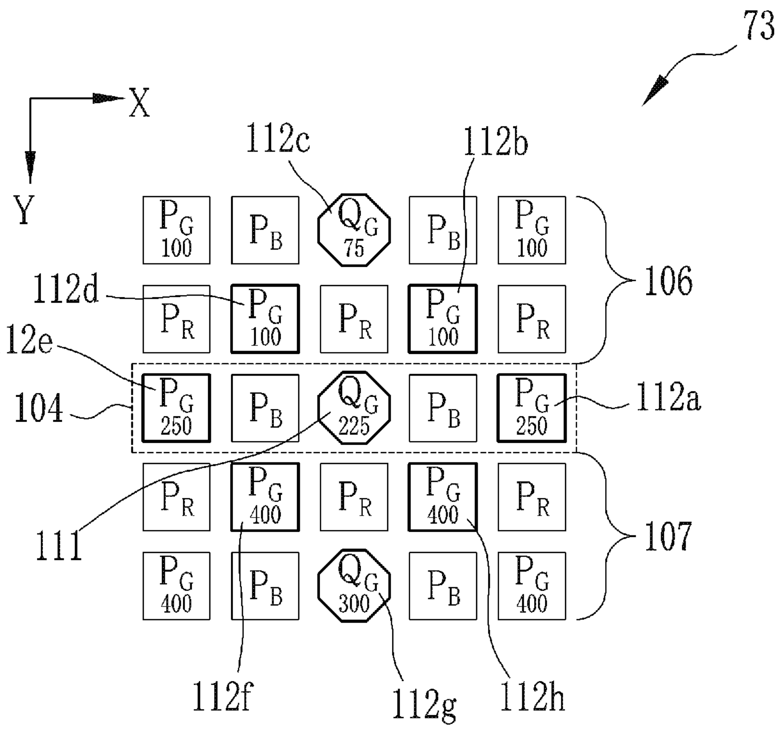

73
X
Y
112c
112b
P_G 100
P_B
Q_G 75
P_B
P_G 100
106
112d
P_R
P_G 100
P_R
P_G 100
P_R
112e
104
P_G 250
P_B
Q_G 225
P_B
P_G 250
112a
P_R
P_G 400
P_R
P_G 400
P_R
107
111
P_G 400
P_B
Q_G 300
P_B
P_G 400
112f
112g
112h

FIG. 19

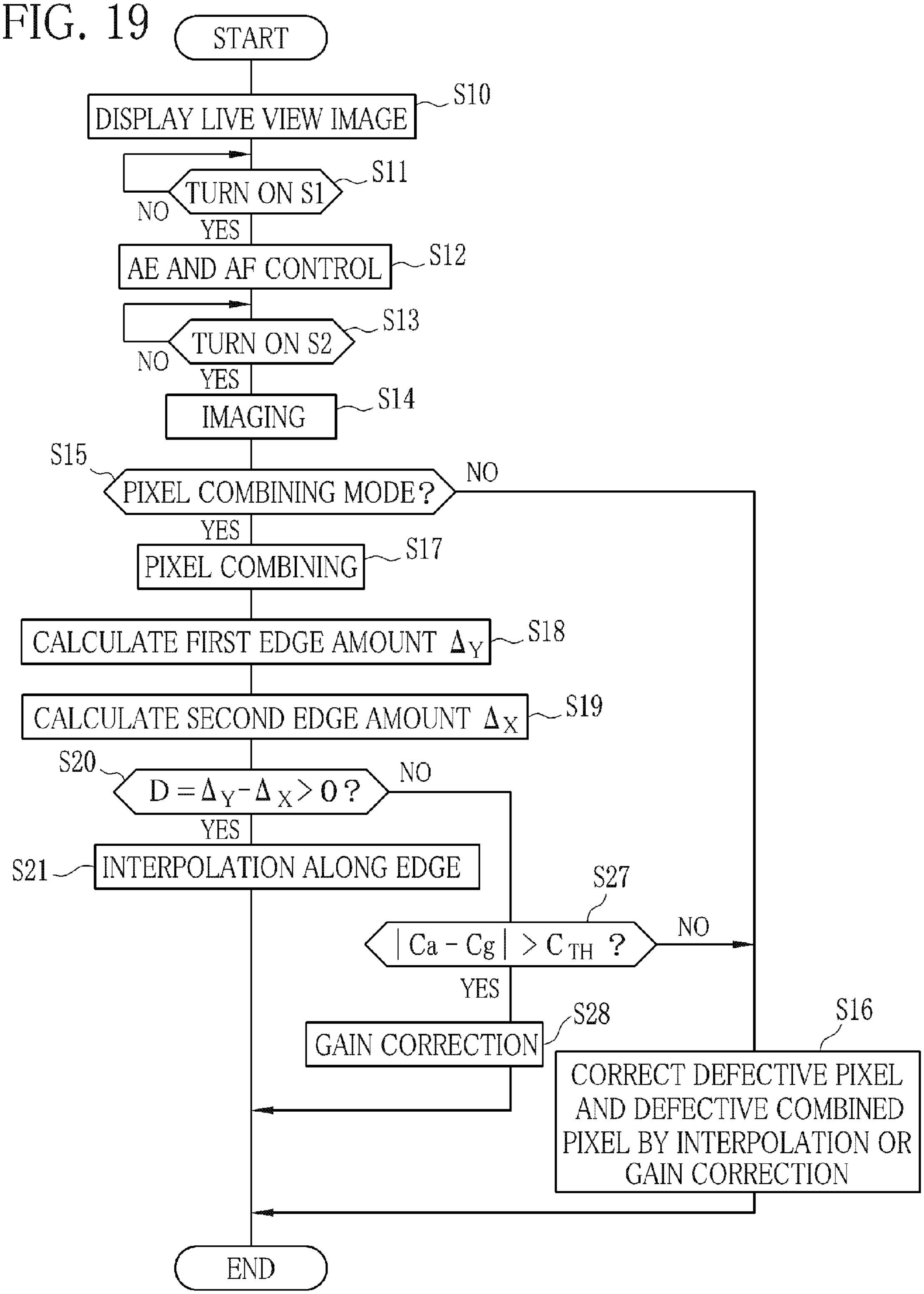

START
DISPLAY LIVE VIEW IMAGE
S10
TURN ON S1
S11
NO
YES
AE AND AF CONTROL
S12
TURN ON S2
S13
NO
YES
IMAGING
S14
S15
PIXEL COMBINING MODE?
NO
YES
PIXEL COMBINING
S17
CALCULATE FIRST EDGE AMOUNT Δ_Y
S18
CALCULATE SECOND EDGE AMOUNT Δ_X
S19
S20
$D=\Delta_Y-\Delta_X>0$?
NO
YES
S21
INTERPOLATION ALONG EDGE
S27
$|Ca-Cg|>C_{TH}$?
NO
YES
GAIN CORRECTION
S28
S16
CORRECT DEFECTIVE PIXEL AND DEFECTIVE COMBINED PIXEL BY INTERPOLATION OR GAIN CORRECTION
END

FIG. 20

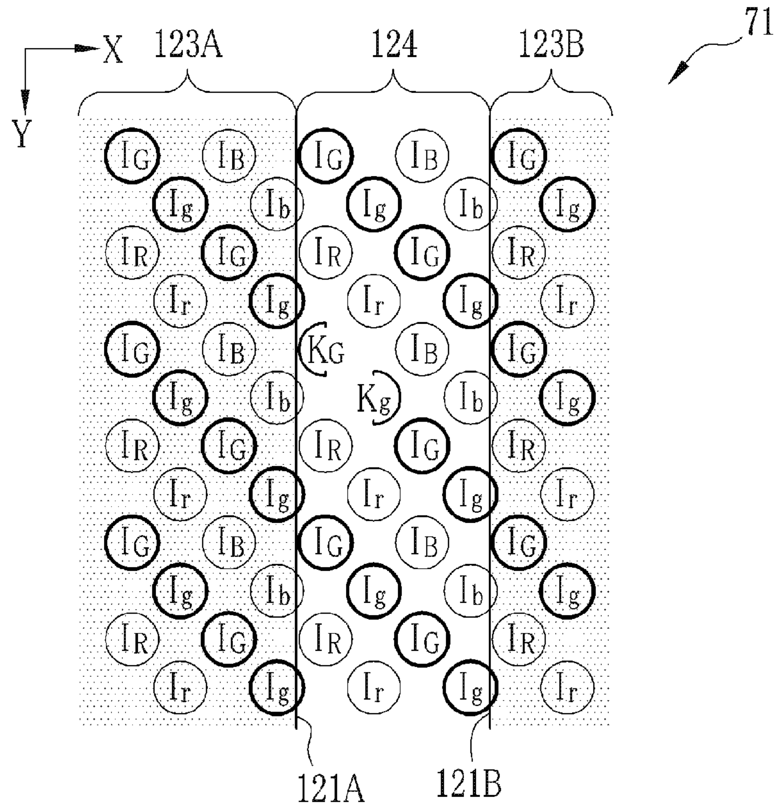

X
Y
123A
124
123B
71
I_G
I_B
I_g
I_b
I_R
I_r
K_G
K_g
121A
121B

FIG. 21

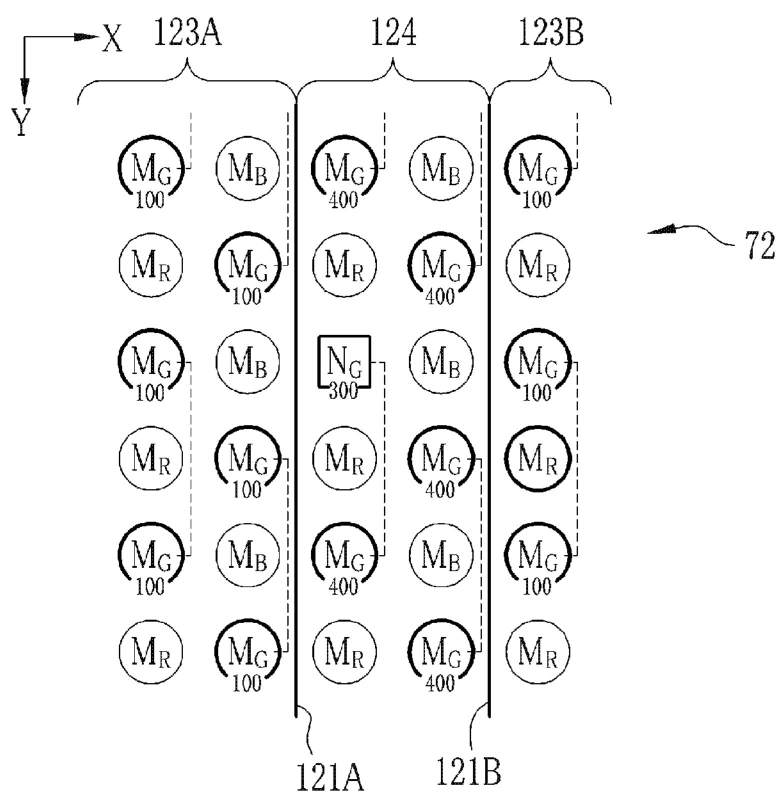
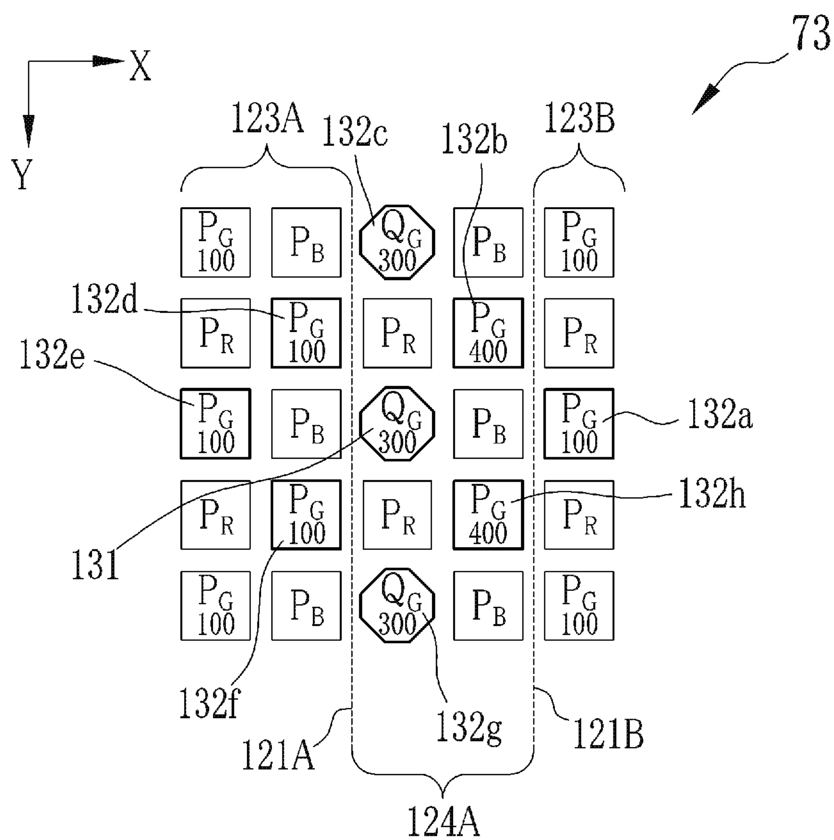

X
Y
123A
124
123B
72
M_G
M_B
M_R
N_G
100
400
300
121A
121B

FIG. 22



73
X
Y
123A
132c
132b
123B
P_G 100
P_B
Q_G 300
P_B
P_G 100
132d
P_R
P_G 100
P_R
P_G 400
P_R
132e
P_G 100
P_B
Q_G 300
P_B
P_G 100
132a
P_R
P_G 100
P_R
P_G 400
P_R
132h
131
P_G 100
P_B
Q_G 300
P_B
P_G 100
132f
121A
132g
121B
124A

PIXEL CORRECTION METHOD AND IMAGE CAPTURE DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation of PCT International Application No. PCT/JP2013/084023 filed on Dec. 19, 2013, which claims priority under 35 U. S. C. §119 (a) to Japanese Patent Application No. 2012-287317, filed Dec. 28, 2012. Each of the above application(s) is hereby expressly incorporated by reference, in its entirety, into the present application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method for correcting defective combined pixel signals generated from pixel signals of phase difference pixels used for focus detection and an image capture device.

2. Description Related to the Prior Art

An autofocusing (AF) function for performing automatic focus adjustment has become a standard feature of image capture devices such as digital cameras and surveillance cameras. Autofocusing functions include a contrast AF operation that performs focus adjustment to make the contrast of the image maximum and a phase detection AF operation that performs the focus adjustment based on a phase difference caused by parallax. The contrast AF operation requires finding an inflection point of the contrast while a taking lens is moved, whereas the phase detection AF operation enables fast autofocusing because it detects the focus state at each lens position.

The image capture device which adopted the phase detection AF operation uses an image sensor (solid-state imaging device) which has pixels (hereinafter referred to as the normal pixels) of symmetrical structure and pixels (hereinafter referred to as the phase difference pixels) of asymmetrical structure used for focus detection. The normal pixels are used for obtaining pixel signals (pixel values) for producing an image (normal image) taken in the normal mode. The phase difference pixels are used for obtaining information of phase difference used for the phase difference AF operation. The phase difference pixel has an opening at the position shifted to the left or right relative to that of the normal pixel, and selectively receives light incident on a right portion or a left portion of a photodiode.

In the case where the taking lens is set in the focusing position, the waveform of the pixel signal read out from the right phase difference pixel group for receiving the light from the right side coincides with the waveform of the pixel signal read out from the left phase difference pixel group for receiving the light from the left side, and there is no phase difference between them. In the case where the taking lens is out of the focusing position, a phase difference appears in the waveforms of the two pixel signals in accordance with defocus. The sequences of the phases of the two pixel signal waveforms which correspond to the front and rear focuses, respectively, differ from each other. Therefore the information of the phase difference is extracted to set the taking lens to the focusing position.

It is common for the image sensor having the phase difference pixels to produce the normal image with the use of the phase difference pixels in addition to the normal pixels because pixel missing occurs at the positions corresponding to the phase difference pixels in the normal image in the case

where the normal image is produced based only on the pixel signals from the normal pixels. However, the pixel signals obtained, without correction, from the phase difference pixels cannot be used as the pixel signals for the normal image because the sensitivity and the like of the phase difference pixels differ from those of the normal pixels. In order to produce the normal image, the pixel having the pixel signal obtained from the phase difference pixel is treated as a defective pixel and the pixel signal is subjected to a correction process. For example, in the case of a color normal image, a method (hereinafter referred to as the interpolation correction) for generating a corrected pixel signal through interpolation using the pixel signals of the adjacent normal pixels of the same color and a method (hereinafter referred to as the gain correction) for multiplying the pixel signal of the phase difference signal by a gain are known (see Japanese Patent Laid-Open Publication Nos. 2012-004729 and 2011-007882, and U. S. Patent Application Publication No. 2011/0109775 (corresponding to Japanese Patent Laid-Open Publication No. 2010-062640)).

The interpolation correction works well with an inconspicuous trace of the correction in the case where a change in a subject is small at around the phase difference pixel. The gain correction works well in the case where a change in a subject is large at around the phase difference pixel. In order to correct the pixel signal of the phase difference pixel, a proper correction method is selected in accordance with the characteristics of the subject located at or around the phase difference pixel.

For example, in the Japanese Patent Laid-Open Publication No. 2012-004729, a change (edge) in a subject at around the phase difference pixel is detected, and the suitable one of the interpolation correction and the gain correction is used in consideration of a gamma correction process performed afterwards. In the Japanese Patent Laid-Open Publication No. 2011-007882, a change (or the direction of a change) in a subject is detected at around the phase difference pixel, and then the suitable one of the interpolation correction and the gain correction is selected. In particular, in the case where the pixel signal of the phase difference signal is corrected through the interpolation correction, it is disclosed that only the normal pixels located in the direction of the change in the subject are used. In the U.S. Patent Application Publication No. 2011/109775, weights of certain proportions are assigned to the pixel signal obtained through the interpolation correction and the pixel signal obtained through the gain correction, respectively, and then the pixel signals are summed. Thereby a corrected pixel signal is obtained. The proportions of the weights are changed based on the change (or uniformity), in the subject, at around the phase difference pixel.

A recent image capture device which executes a normal mode in which a normal image with high resolution is produced and a pixel combining mode that allows imaging with high sensitivity despite the low resolution has been known (see Japanese Patent Laid-Open Publication No. 2011-250325). In the pixel combining mode, the pixel signals of two or more pixels are combined with each other to generate a pixel signal of one combined pixel. Combining the pixel signals is referred to as a pixel addition process or a pixel combining process.

In the pixel combining mode, a composite image is produced by combining the pixel signals under a certain rule. For example, the color image sensor combines the pixel signals of two pixels disposed side by side in a certain direction, out of the pixels of the same color disposed close to each other. In the case where this pixel combining process is applied to the phase difference pixel in a like manner, there are three patterns of combinations, depending on the arrangement of the phase difference pixels: a normal pixel and another normal pixel; a normal pixel and a phase difference pixel; a phase difference pixel and another phase difference pixel. In the two patterns in which the pixel signal of the phase difference pixel is added (excluding the pattern in which the normal pixels are combined with each other) out of the three patterns of the combinations, a new combined pixel that is generated by the pixel combining process is a defective combined pixel, so that the correction of the pixel signal thereof is necessary. In other words, in the color image sensor having the phase difference pixels, the number of the defective combined pixels in the pixel combining mode is greater than the number of the phase difference pixels, being the defective pixels, in the normal image. Therefore the pixel combining mode requires a long time to correct the pixel signals as compared with the normal mode. In the Japanese Patent Laid-Open Publication No. 2011-250325, the arrangement of the phase difference pixels in the color image sensor is improved such that the pixel combining process which involves the phase difference pixel is performed by combining the phase difference pixels of the same color. Thus, there are only two patterns of combinations: a normal pixel and another normal pixel; a phase difference pixel and another phase difference pixel.

In the case where the phase difference pixels are disposed consecutively in the image sensor, the pixel signals from the phase difference pixels may not be corrected accurately in the image data (data composed of the pixel signals of one frame) of the normal image. For example, in the case where the interpolation correction is suitable for correcting the pixel signals of the phase difference pixels, the pixel signals of the normal pixels adjacent to the phase difference pixels are used. In the case where the phase difference pixels are disposed consecutively, the normal pixels necessary for the interpolation correction may be in short supply or the direction in which accurate interpolation is allowed may be limited. As a result, the correction accuracy may be degraded and the trace of the correction may become conspicuous.

In the normal mode, in order to ensure the accuracy of the interpolation correction, it is preferred that, at least, all of the pixels of the same color disposed in the closest proximity to the phase difference pixel are the normal pixels. This means that one or more normal pixels of the same color as that of the phase difference pixel are disposed between the phase difference pixels. In this case, however, the pixel signal of the phase difference pixel is combined with the pixel signal of the normal pixel in the pixel combining mode.

Since a pixel which is based on the pixel signal obtained from the phase difference pixel is a defective pixel, a pixel which is based on the pixel signal obtained by combining the pixel signal of the phase difference pixel with the pixel signal of the normal pixel is a defective combined pixel. In this case, the number of the defective combined pixels is increased, resulting in long correction time. Characteristics of the defective combined pixel differ from those of the defective pixel that is based on the phase difference pixel. The pixel signal of the defective combined pixel cannot be corrected accurately by the same method as that for correcting the phase difference pixel. For example, in a composite image obtained in the pixel combining mode, the pixel signal of the defective combined pixel, which is obtained by combining the pixel signal of the phase difference pixel with the pixel signal of the normal pixel across the edge (the boundary across which the pixel signal changes abruptly) of the subject requires long correction time. Furthermore, even if the interpolation correction and the gain correction for correcting the pixel signal of the phase difference pixel are applied to the defective combined pixel, the result of the correction often turns out to be inaccurate.

To prevent the above-described problems, in the Japanese Patent Laid-Open Publication No. 2011-250325, the arrangement of the phase difference pixels is improved to inhibit combining the pixel signal of the normal pixel with the pixel signal of the phase difference pixel. However, it is impossible to inhibit combining the pixel signal of the normal pixel with the pixel signal of the phase difference pixel. Therefore it is required to accurately correct the pixel signal of the defective combined pixel, which is generated by combining the pixel signal of the normal pixel and the pixel signal of the phase difference pixel.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a method for accurately correcting a pixel signal of a defective combined pixel which is generated by combining a pixel signal of a normal pixel and a pixel signal of a phase difference pixel and an image capture device.

An image capture device of the present invention comprises a color image sensor, a pixel combining unit, an edge detector, and a corrector. The color image sensor has a plurality of normal pixels and two or more phase difference pixels. The normal pixel isotropically receives incident light. The phase difference pixel selectively receives a part of the incident light. The pixel combining unit performs a same type combining process and a different type combining process to produce a composite image. In the same type combining process, first pixel signals from the normal pixels of the same color are combined with each other or second pixel signals from the phase difference pixels of the same color are combined with each other, to generate a first combined signal. In the different type combining process, the first pixel signal and at least one of the second pixel signals of the same color are combined to generate a second combined signal. The composite image is composed of a first combined pixel that is based on the first combined signal and a second combined pixel that is based on the second combined signal. The edge detector detects an edge of a subject by detecting a first direction in which a difference between the first pixel signal and the second pixel signal of the same color or a difference between the first combined signal and the second combined signal of the same color is at a maximum. The edge is vertical to the first direction. The corrector corrects the second combined signal of the second combined pixel through an interpolation process using the first combined signal of the first combined pixel in a case where the different type combining process is performed across the edge, the first combined pixel being disposed in a second direction which is along the edge and vertical to the first direction, the first combined pixel having the same color as the second combined pixel to be corrected.

It is preferred that there are at least three types of the normal pixels corresponding three primary colors, respectively. There is at least one type of the phase difference pixels corresponding to one of the three primary colors.

It is preferred that the corrector calculates an average value of the first combined signals of the first combined pixels and replaces the second combined signal of the second combined pixel to be corrected, with the average value. The first combined pixels are disposed in a second direction which is along the edge and vertical to the first direction. The first combined pixels have the same color as the second combined pixel to be corrected.

It is preferred that the pixel combining unit generates the first combined signal through combining the four first pixel signals of the same color or the four second pixel signals of the same color in the same type combining process, and generates the second combined signal through combining four of the first and second pixel signals including at least a pair of the first and second pixel signals in the different type combining process.

It is preferred that the pixel combining unit generates the first combined signal through combining the two first pixel signals of the same color or the two second pixel signals of the same color in the same type combining process, and generates the second combined signal through combining the one first pixel signal with the one second pixel signal in the different type combining process.

It is preferred that the edge detector calculates the difference in each of a specific direction extending between the normal pixel for generating the first pixel signal and the phase difference pixel for generating the second pixel signal and another direction vertical to the specific direction, and the first pixel signal and the second pixel signal are combined in the different type combining process.

It is preferred that, in order to calculate the difference, the edge detector uses the first combined signals of the first combined pixels disposed opposite to each other with respect to the second combined pixel to be corrected.

It is preferred that the color image sensor has a first pixel group, in which the plurality of pixels are arranged in a square matrix, and a second pixel group, in which the plurality of pixels are arranged in a square matrix at the same arrangement pitch as the first pixel group. The pixels in the second pixel group are disposed in positions obliquely shifted from positions of the pixels in the first pixel group, respectively. The first pixel group and the second pixel group are provided with color filters of the same color arrangement.

It is preferred that the phase difference pixel of the first pixel group and the phase difference pixel of the second pixel group are of the same color and adjacent to each other in an oblique direction.

It is preferred that every fourth pixel in row direction and column direction of each of the square matrices is the phase difference pixel, and the normal pixel of the same color and the same pixel group as the phase difference pixel is disposed between the phase difference pixels.

A pixel correction method comprises an imaging step, a pixel combining step, an edge detecting step, and a correcting step. In the imaging step, a subject is imaged with a color image sensor having a plurality of normal pixels and two or more phase difference pixels. The normal pixel isotropically receives incident light. The phase difference pixel selectively receives a part of the incident light. In the edge detecting step, a same type combining process and a different type combining process are performed to produce a composite image. In the same type combining process, first pixel signals from the normal pixels of the same color are combined with each other or second pixel signals from the phase difference pixels of the same color are combined with each other, to generate a first combined signal. In the different type combining process, the first pixel signal and at least one of the second pixel signals of the same color are combined with each other to generate a second combined signal. The composite image is composed of a first combined pixel that is based on the first combined signal and a second combined pixel that is based on the second combined signal. In the edge detecting step, an edge of the subject is detected by detecting a first direction in which a difference between the first pixel signal and the second pixel signal of the same color or a difference between the first combined signal and the second combined signal of the same color is at a maximum. The edge is vertical to the first direction. In the correcting step, the second combined signal of the second combined pixel is corrected through an interpolation process using the first combined signal of the first combined pixel in a case where the different type combining process is performed across the edge. The first combined pixel is disposed in a second direction which is along the edge and vertical to the first direction. The first combined pixel has the same color as the second combined pixel to be corrected.

According to the present invention, the same type combining process, in which the pixel signals of the normal pixels of the same color are combined with each other, and the different type combining process, in which the pixel signals of the phase difference pixel and the normal pixel of the same color are combined with each other, are performed. A direction in which the difference between the pixel signals is at the maximum is detected to detect the edge of the subject. In the case where the different type combining process is performed across the edge, the pixel signal of the second combined pixel, being the defective combined pixel, is corrected through the interpolation process using the pixel signals of the first combined pixels of the same color which exist in the direction of the edge. Thus, the pixel signal of the second combined pixel is corrected properly.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects and advantages of the present invention will be more apparent from the following detailed description of the preferred embodiments when read in connection with the accompanied drawings, wherein like reference numerals designate like or corresponding parts throughout the several views, and wherein:

FIG. **1** is a perspective view of a digital camera seen from its front side;

FIG. **2** is a back view of the digital camera;

FIG. **3** is a block diagram illustrating electric configuration of the digital camera;

FIG. **4** is an explanatory view illustrating configuration of a color image sensor;

FIG. **5** is a circuit diagram illustrating electric configuration of a pixel;

FIG. **6** is a cross-sectional view of a normal pixel;

FIG. **7** is a cross-sectional view of a phase difference pixel provided in a first pixel group;

FIG. **8** is a cross-sectional view of a phase difference pixel provided in a second pixel group;

FIG. **9** is an explanatory view illustrating an arrangement of pixels in a normal image;

FIG. **10** is an explanatory view illustrating an arrangement of pixels in a first composite image;

FIG. **11** is an explanatory view illustrating an arrangement of pixels in a second composite image;

FIG. **12** is a block diagram illustrating configuration of a pixel signal correction processor;

FIG. **13** is an explanatory view illustrating a region for calculating a gain;

FIG. **14** is an explanatory view illustrating pixels used for correction through interpolation and edge detection;

FIG. **15** is a flowchart illustrating steps for correcting a pixel signal of a phase detection pixel or a defective combined pixel;

FIG. **16** is an explanatory view illustrating an arrangement of the pixels in a normal image in a case where an edge of a subject is parallel to the X direction;

FIG. **17** is an explanatory view illustrating an arrangement of the pixels in the first composite image in the case where the edge of the subject is parallel to the X direction;

FIG. **18** is an explanatory view illustrating an arrangement of the pixels in the second composite image in the case where the edge of the subject is parallel to the X direction;

FIG. **19** is a flowchart illustrating steps for correcting the phase difference pixel or the defective combined pixel according to a modified example of the present invention;

FIG. **20** is an explanatory view illustrating an arrangement of the pixels in a normal image in the case where a subject with vertical stripes is imaged;

FIG. **21** is an explanatory view illustrating an arrangement of the pixels in a first composite image in the case where the subject with the vertical stripes is imaged; and

FIG. **22** is an explanatory view illustrating an arrangement of the pixels in a second composite image in the case where the subject with the vertical stripes is imaged.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. **1** and **2** illustrate a digital camera **11** as an example of an image capture device. The digital camera **11** comprises a camera body **12** and a lens barrel **13**. The camera body **12** comprises a flash emitter **14**, an operation unit **15**, and a display section **16**. The lens barrel **13** is provided on the front face of the camera body **12** and holds a taking lens **17**.

The flash emitter **14** is provided on the front face of the camera body **12**. In a low-luminance automatic flash mode and an always-on mode, the flash emitter **14** applies light to a subject in synchronization with image capture. The operation unit **15** comprises a power switch **18**, a release button **19**, a mode selection button **20**, and the like. The power switch **18** is operated to turn the power of the digital camera **11** on or off.

The release button **19** is pressed to execute imaging. The release button **19** is a two-step down switch composed of an S**1** switch (which is to be half-pressed), and an S**2** switch (which is to be fully pressed). Upon turning on the S**1** switch in response to half-pressing of the release button **19**, the digital camera **11** automatically performs the focus adjustment and calculation of an exposure amount. In response to turning on the S**2** switch, the imaging is performed based on the exposure amount in the imaging mode chosen (set).

The mode selection button **20** is operated to switch the operation mode of the digital camera **11**. The operation modes of the digital camera **11** include a still image capture mode for taking still images, a movie capture mode for taking movies, a reproduction mode for reproducing and displaying the taken still images or movies on the display section **16**, and the like. The still image capture mode includes a normal mode for producing a normal image with high resolution, a pixel combining mode for producing a composite image with high sensitivity, a wide dynamic range mode for producing an image with a wide dynamic range, and the like.

The display section **16** is composed of a liquid crystal display and the like provided on the back face of the camera body **12**. The images taken in various imaging modes, a menu screen for performing settings, or the like are displayed.

As illustrated in FIG. **3**, the taking lens **17**, a mechanical shutter **24**, an aperture stop **21**, and the like are provided in the lens barrel **13**. In FIG. **3**, the taking lens **17** is schematically depicted with one optical lens, but actually has two or more optical lenses such as a focusing lens for focus adjustment and a variable power lens for adjusting the focal length. The lens barrel **13** is provided with a lens driver **22** and a mechanical shutter and aperture stop driver **23**. The lens driver **22** moves each optical lens of the taking lens **17** to adjust the position of each optical lens in an optical axis direction. The mechanical shutter and aperture stop driver **23** opens or shuts the mechanical shutter **24** and adjusts the aperture size of the aperture stop **21**.

A color image sensor **26** is provided on the light exit side of the lens barrel **13**. The color image sensor **26** is a color single CMOS solid-state imaging device. The color image sensor **26** has a light receiving area **40***a* (see FIG. **4**) on which an image of a subject is formed. A plurality of normal pixels and a plurality of phase difference pixels are arranged in a matrix in the light receiving area **40***a*. The color image sensor **26** is driven by an image sensor driver **27**, and one color pixel signal (hereinafter simply referred to as the pixel signal) is read out from each pixel. The pixel signals of one frame are digitally converted into image data (the so-called RAW data). The RAW data corresponds to the imaging mode chosen by operating the mode selection button **20**. For example, the RAW data outputted in the normal mode is composed of the pixel signals outputted from the respective pixels of the image sensor **26**. In the pixel combining mode, the RAW data is composed of pixel signals in which the pixel signals of the respective pixels of the image sensor **26** are combined based on a specific rule.

A CPU **25** controls the digital camera **11** based on operation signals inputted from the operation unit **15**. For example, the CPU **25** controls the operations of the lens driver **22**, the mechanical shutter and aperture stop driver **23**, and the image sensor driver **27**. The CPU **25** controls the flash emitter **14** to flash in synchronization with imaging.

The CPU **25** is connected to a control bus **28**, and controls a memory controller **30**, an AF detector **31**, a pixel signal processor **32**, a compression/decompression processor **33**, a media controller **34**, a display controller **35**, and the like, which are connected to the control bus **28**.

A memory **36** for temporary storage such as SDRAM is connected to the memory controller **30**. The memory controller **30** inputs the RAW data outputted from the color image sensor **26** to the memory **36**. The RAW data stored in the memory **36** is read out to the AF detector **31** and the pixel signal processor **32** through a data bus **29**.

The AF detector **31** calculates a focus evaluation value, which represents information related to parallax, based on the pixel signals outputted from two or more phase difference pixels in the RAW data, as is well known. The CPU **25** drives the lens driver **22** based on the focus evaluation value obtained from the AF detector **31** to move the focusing lens of the taking lens **17** to a focusing position.

The pixel signal processor **32** performs various processes such as an image signal correction process for correcting pixel signals from the phase difference pixels (or combined pixel signals in which the pixel signals from the phase difference pixels are combined), a demosaicing process, a gamma correction process, and an RGB/YCrCb conversion process (see FIG. **12**) on the RAW data. After being subjected to these processes, the image data is displayed on the display section **16** through the display controller **35**, for example. The compression/decompression processor **33** compresses the image data which has been processed by the pixel signal processor **32**, in a given format such as JPEG.

A recording medium **37** composed of a non-volatile memory such as a flash memory is connected to the media controller **34**. The media controller **34** stores various types of image data such as the RAW data and the compressed image data in the recording medium **37** in the given format. In the reproduction mode, the media controller **34** reads the image data from the recording medium **37**.

As illustrated in FIG. **4**, the color image sensor **26** comprises an image capture section **40**, a vertical scanning circuit **41** for reading, a reset circuit **42**, a horizontal scanning circuit **43**, an output amplifier **44**, an A/D converter **45**, and a pixel combining circuit (pixel combining unit) **46**. The image capture section **40** comprises a plurality of pixels (which may also be called as picture elements) **50** in the light receiving area **40***a*. The pixels **50** are arranged two-dimensionally in X and Y directions, which are orthogonal to each other.

The pixels (which may also be called as picture elements) **50** include two types of pixels, normal pixels **51***a* and **51***b* and phase difference pixels **52***a* and **52***b*. The normal pixels **51***a* and the phase difference pixels **52***a* are disposed in odd-numbered rows and constitute a first pixel group. The normal pixels **51***b* and the phase difference pixels **52***b* are disposed in even-numbered rows and constitute a second pixel group. In each of the first pixel group and the second pixel group, the pixels **50** are arranged in a square matrix at a pitch P in the row direction (X direction) and the column direction (Y direction). The pixels **50** (the normal pixels **51***b* and the phase difference pixels **52***b*) of the second pixel group are shifted from the pixels **50** (the normal pixels **51***a* and the phase difference pixels **52***a*) of the first pixel group by a half pitch (P/2) in the X and Y directions. The pixels **50** in the first and second pixel groups constitute a so-called honeycomb array as a whole.

Each pixel **50** is provided with one of red filter, green filter, and blue filter, which differ from each other in spectral transmittance. The capital letters "R" (red), "G" (green), and "B" (blue) denote the colors of the color filters provided to the pixels **50** of the first pixel group. The small letters "r" (red), "g" (green), and "b" (blue) denote the colors of the color filters provided to the pixels **50** of the second pixel group. Each color filter transmits light in a wavelength range of the corresponding color. The color arrangement of the color filters of the first pixel group is the same as that of the second pixel group. In this embodiment, the color filters in each of the first and second pixel groups are in the Bayer arrangement. The pixel **50** (of the first pixel group) and the pixel **50** (of the second pixel group) adjacent in an oblique direction have the color filters of the same color.

The phase difference pixel **52***a* of the first pixel group has the G filter. Every fourth pixel in each of X and Y directions is the phase difference pixel **52***a* with the G filter. The phase difference pixel **52***b* of the second pixel group has the g filter. Every fourth pixel in each of X and Y directions is the phase difference pixel **52***b* with the g filter. The phase difference pixel **52***a* of the first pixel group is adjacent to the phase difference pixel **52***b* of the second pixel group and these two pixels constitute a pair.

The phase difference pixel **52***a* of the first pixel group is a left phase difference pixel that selectively receives light incident on the left side thereof of the isotropic incident light. The phase difference pixel **52***b* of the second pixel group is a right phase difference pixel that selectively receives light incident on the right side thereof. At the time of AF control, the pair of pixel signals outputted from the left and right phase difference pixels is extracted from the RAW data, and used for calculating the focus evaluation value by the AF detector **31**. In order to produce an image, which is to be displayed or stored, based on the RAW data, the pixel signal processor **32** corrects the pixel signal from the phase difference pixel **52***a*, the pixel signal from the phase difference pixel **52***b*, or the pixel signal from the combined pixel signal, which is obtained by adding the pixel signal from the phase difference pixel **52***a* and/or the pixel signal from the phase difference pixel **52***b*.

The pixels other than the phase difference pixels **52***a* and **52***b* of the first and second pixel groups are the normal pixels **51***a* and **51***b*. The normal pixels **51***a* and **51***b* receive the incident light evenly or isotropically. Since every fourth pixel of the first pixel group is the phase difference pixel **52***a* of the first pixel group, the normal pixel **51***a* with the G filter, which is of the same color as the G filter of the phase difference pixel **52***a*, is disposed between the closest phase difference pixels **52***a*. In a like manner, every fourth pixel of the second pixel group is the phase difference pixel **52***b* of the second pixel group, so that the normal pixel **51***b* with the G filter, which is of the same color as the G filter of the phase difference pixel **52***b*, is disposed between the closest phase difference pixels **52***b*.

The vertical scanning circuit **41** sequentially outputs a row selection signal to each row of the pixels in the image capture section **40**. The reset circuit **42** sequentially outputs a reset signal to each row of the pixels. The reset circuit **42** is capable of collectively outputting the reset signals to the entire first pixel group or the entire second pixel group independently.

The horizontal scanning circuit **43** sequentially outputs a column selection signal and sequentially transfers the pixel signal, which is outputted from each pixel **50** of the pixel row selected by the row selection signal, to the output amplifier **44**. The output amplifier **44** amplifies the pixel signal and then inputs the pixel signal to the A/D converter **45**. The A/D converter **45** digitally converts the pixel signal and outputs the digitally converted pixel signal. In the normal mode, the pixel signal from the A/D converter **45** is outputted as the RAW data. In the pixel combining mode and the wide dynamic range mode, the pixel signal from the A/D converter **45** is inputted to the pixel combining circuit **46**.

The pixel combining circuit **46** comprises a first pixel combiner **46***a* and a second pixel combiner **46***b*. The first pixel combiner **46***a* performs a first pixel combining process in which the pixel signals of the obliquely adjacent pixels of the same color of the first and second pixel groups are added. After the first pixel combining process, the second pixel combiner **46***b* performs a second pixel combining process in which the pixel signals of the pixels of the same color which are adjacent (in close proximity) in the column direction (Y direction) are added. In the pixel combining mode for obtaining an image with high sensitivity, the combined pixel signal, in which four pixel signals in total are added by the first and second pixel combiners **46***a* and **46***b*, is outputted as the RAW data to the data bus **29**. In the wide dynamic range mode, the combined pixel signal obtained through the first pixel combining process performed by the first pixel combiner **46***a* is outputted as the RAW data to the data bus **29**.

As illustrated in FIG. **5**, each pixel **50** comprises a photodiode (photoelectric conversion element) PD, a reset transistor RTr, an amplifying transistor ATr, and a select transistor STr. Thus, each pixel **50** has 3-transistor configuration. Each transistor is an n-type MOS transistor, for example.

Each pixel **50** is connected to two drive lines: a row selection line **53** and a reset line **54**. Each of the row selection line **53** and the reset line **54** is connected to the pixels **50** of the same row. An end of the row selection line **53** is connected to the vertical scanning circuit **41**. An end of the reset line **54** is connected to the reset circuit **42**.

Each pixel **50** is connected to a signal line **55**. The signal line **55** is connected to the pixels **50** of the same column. An end of the signal line **55** is connected to the horizontal scanning circuit **43**.

The photodiode PD photoelectrically converts the received light into a charge which corresponds to the amount of the received light. The anode of the photodiode PD is connected to ground. The cathode of the photodiode PD is connected to the gate electrode of the amplifying transistor ATr. A floating diffusion FD is formed in a connect section between the cathode of the photodiode PD and the gate electrode of the amplifying transistor ATr. The floating diffusion FD stores the charge generated by the photodiode PD.

The source electrode of the reset transistor RTr is connected to the floating diffusion FD. The drain electrode of the reset transistor RTr is connected to a power supply voltage VDD. The reset transistor RTr is turned on by supplying the reset signal to the gate electrode through the reset line RST. When the reset transistor RTr is turned on, the power supply voltage VDD is applied to the floating diffusion FD, and thereby the stored charge is discharged.

The gate electrode of the amplifying transistor ATr is connected to the floating diffusion FD. The power supply voltage VDD is applied to the drain electrode of the amplifying transistor ATr. The amplifying transistor ATr outputs the pixel signal (pixel value), which corresponds to the charge stored in the floating diffusion FD, from the source electrode.

The drain electrode of the select transistor STr is connected to the source electrode of the amplifying transistor ATr. The source electrode of the select transistor STr is connected to the signal line **55**. The select transistor STr is turned on by supplying the row selection signal to the gate through the row selection line **53**. When the select transistor STr is turned on, the pixel signal which is outputted from the source electrode of the amplifying transistor ATr is outputted to the signal line **55**.

Rolling shutter operation and global shutter operation are the exposure operations of the image capture section **40**. In the rolling shutter operation, the mechanical shutter **24** is in the open state. The vertical scanning circuit **41** supplies a row selection signal to each pixel row through the row selection line **53**, and the reset circuit **42** supplies a reset signal to each pixel row through the reset line **54**. While the row selection signal is supplied to the pixel row, the horizontal scanning circuit **43** sequentially reads out the pixel signal outputted to each signal line **55** and the reset signal is supplied to the preceding pixel row. The reading operation and the reset operation are repeated while the pixel rows to be subjected to the reading and reset operations are shifted. Thereby, the image data of one frame or more is obtained. The rolling shutter operation is performed in the AF operation and in the movie mode.

In the global shutter operation, the mechanical shutter **24** is in the open state. The reset signals are collectively supplied to the first and second pixel groups. Thereby collective reset is performed. Then, after a predetermined time period, the mechanical shutter **24** is closed. The pixel signal of each pixel is read out in time series by supplying a row selection signal to each pixel row with the mechanical shutter **24** closed. Thus, the image data of one frame is obtained. The global shutter operation is used in the normal mode and the pixel combining mode.

In the global shutter operation in the wide dynamic range mode, the timing for supplying the reset signal to the first pixel group differs from the timing for supplying the reset signal to the second pixel group. Thereby the exposure time of the first pixel group differs from that of the second pixel group. For example, the first pixel group is set to a long exposure time and the second pixel group is set to a short exposure time. Thereby the pixel signals obtained from the first pixel group are high sensitivity signals. The pixel signals obtained from the second pixel group are low sensitivity signals. The pixel combining circuit **46** combines the high and low sensitivity signals with each other. Thus, the image data with the wide dynamic range is obtained.

Note that the pixel **50** is not limited to the 3-transistor configuration. The pixel **50** may have 4-transistor configuration, in which a transfer transistor is further provided between the photodiode PD and the floating diffusion FD.

As illustrated in FIG. **6**, the color image sensor **26** is a back-side illumination type. In each of the normal pixels **51***a* and **51***b*, the photodiode PD is formed in a p-type semiconductor substrate **60**. A wiring layer **61** is formed on the opposite side of the light incident side of the p-type semiconductor substrate **60**. The wiring layer **61** is provided with electrodes **62**, which are formed from amorphous silicon or the like, and wirings **63** and **64**, which are formed from aluminum or the like. The electrodes **62** and the wirings **63** and **64** constitute the electrodes and the wirings of each of the above-described transistors.

A light shielding layer **65**, which is formed from aluminum or the like, is provided on the light incident side of the p-type semiconductor substrate **60**. In each of the normal pixels **51***a* and **51***b*, a normal opening **65***a* is disposed in the light shielding layer **65**, at the position corresponding to the position of the photodiode PD. The center of the normal opening **65***a* is substantially coincident with the center of the photodiode PD. The entire surface of the photodiode PD on the light incident side is exposed through the normal opening **65***a*.

A color filter (in this example, the G filter) is provided on the light incident side of the light shielding layer **65**. A microlens **66** is formed on the light incident side of the color filter. The color filter is formed from a resin material in which a dye or a pigment is dispersed. The microlens **66** is formed from silicon dioxide or a transparent resin material. The optical axis of the microlens **66** is substantially coincident with the center of the photodiode PD. The microlens **66** collects the incident light on the photodiode PD. Of the light exited from the microlens **66**, only the light of the color separated by the color filter of the corresponding color passes through the normal opening **65***a* and then enters the photodiode PD.

Each of the normal pixels **51***a* and **51***b* receives both of incident light L**1**, which is incident from the left side, and incident light L**2**, which is incident from the right side. In other words, the normal pixels **51***a* and **51***b* receive the incident light evenly and isotropically.

As illustrated in FIG. **7**, in the phase difference pixel **52***a* of the first pixel group, a first off-center opening **65***b* is disposed in the light shielding layer **65**, at the position corresponding to the position of the photodiode PD. The center of the first off-center opening **65***b* is shifted to the right from the center of the photodiode PD. Only a part of the surface of the photodiode PD on the light incident side is exposed through the first off-center opening **65***b*.

Thereby, in the phase difference pixel **52***a* of the first pixel group, the incident light L**1**, which is incident from the left side is blocked by the light shielding layer **65**. The incident light L**2**, which is incident from the right side, passes through the first off-center opening **65***b* and enters the photodiode PD. Thus, the phase difference pixel **52***a* of the first pixel group selectively receives the incident light L**2**, which is incident from the right side. Other than the component described above, the components of the phase difference pixel **52***a* of the first pixel group are the same as or similar to those of the normal pixels **51***a* and **51***b*.

As illustrated in FIG. **8**, in the phase difference pixel **52***b* of the second pixel group, a second off-center opening **65***c* is disposed in the light shielding layer **65**, at the position corresponding to the position of the photodiode PD. The center of the second off-center opening **65***c* is shifted to the left from the center of the photodiode PD. Only a part of the surface of the photodiode PD on the light incident side is exposed through the second off-center opening **65***c*.

Thereby, in the phase difference pixel **52***b* of the second pixel group, the incident light L**2**, which is incident from the right side, is blocked by the light shielding layer **65**. The incident light L**1**, which is incident from the left side, passes through the second off-center opening **65***c* and enters the photodiode PD. Thus, the phase difference pixel **52***b* of the second pixel group selectively receives the incident light L**1**, which is incident from the left side. Other than the component described above, the components of the phase difference pixel **52***b* of the second pixel group are the same as or similar to those of the normal pixels **51***a* and **51***b*.

Each of the phase difference pixels **52***a* and **52***b* of the first and second pixel groups selectively receives only the light incident from the left side or the right side, so that the amount of the light received is small and the sensitivity is low as compared with those of the normal pixel **51***a* or **51***b*. The phase difference pixels **52***a* and **52***b* are sensitive to the light incident angles as compared with the normal pixels **51***a* and **51***b*. The properties of the phase difference pixels **52***a* and **52***b* vary (for example, the sensitivities thereof may further increase or decrease) depending on the positions of the phase difference pixels **52***a* and **52***b* in the image capture section **40**. For this reason, the pixel signal of the phase difference pixel **52***a* or **52***b* (or the combined pixel signal in which the pixel signal of the phase difference pixel **52***a* is combined with the pixel signal of the phase difference signal **52***b*) is a defective signal in the image data to be displayed or stored. Therefore such defective signal is distinguished from the pixel signal of the normal pixel **51***a* or **51***b* (or the combined pixel signal in which only the pixel signal of the normal pixel **51***a* is combined with the pixel signal of the normal pixel **51***b*).

Note that the phase difference pixels **52***a* and **52***b* are disposed for the phase detection AF. The defects derived from the phase difference pixels **52***a* and **52***b* are inevitable. The positions of the defects derived from the phase difference pixels **52***a* and **52***b* are predetermined depending on the arrangement of the phase difference pixels **52***a* and **52***b*. Such defects differ from failure (the so-called flaw) which occurs incidentally at random positions during manufacture of the color image sensor **26** or due to the deterioration with time. In this embodiment, the incidental failure is disregarded for the sake of simplicity. Unless otherwise specified, a "defective pixel" refers to a pixel having a pixel signal of the phase difference pixel **52***a* or **52***b*. A "defective combined pixel" refers to a combined pixel which is based on a combined pixel signal obtained by combining the pixel signal of the phase difference pixel **52***a* or **52***b*. A "normal combined pixel" refers to a combined pixel which is based on a combined pixel signal obtained by combining the pixel signals of the normal pixels **51***a* and **51***b*. Note that methods for correcting the incidentally occurring defective pixel values have been known, so that those defective pixel values may be corrected by using a proper method.

Next, a pixel combining process performed by the pixel combining circuit **46** is described. During the imaging performed by the color image sensor **26**, the charge stored in each pixel **50** of the image capture section **40** is read out as the pixel signal. Each pixel signal is digitally converted by the A/D converter **45**, and then transmitted as image data (normal image data) **71** to the pixel combining circuit **46**. As illustrated in FIG. **9**, the image data **71** refers to the pixel signals of one frame. The pixels of the image data **71** corresponds to the pixels **50**, respectively. In the normal mode, the image data **71** is outputted as the RAW data. Characters (letters) in each pixel represent the pixel signal. For example, "I_R", "I_G", and "I_B" represent the pixel signals from the normal pixels **51***a* of the first pixel group. "I_r", "I_g", and "I_b" represent the pixel signals from the normal pixels **51***b* of the second pixel group. "K_G" and "K_g" represent the pixel signals from the phase difference pixels **52***a* and **52***b* of the first and second pixel groups, respectively. Each subscript of the pixel signals I_R, I_G, I_B, I_r, I_g, I_b, K_G, and K_g represents the color of the corresponding color filter. The pixel which is based on the normal pixel **51***a* or **51***b* is depicted with a circle. A pixel based on the phase difference pixel **52***a* or **52***b* is depicted with a semicircle.

In the pixel combining mode and the wide dynamic range mode, the first pixel combiner **46***a* performs a first pixel combining process to generate first composite image data **72** (see FIG. **10**) from the normal image data **71**. In the first pixel combining process, as illustrated with dotted boxes in FIG. **9**, the pixel signals which are obtained from the obliquely adjacent pixels of the same color of the first and second pixel groups are added or averaged. To be more specific, the pixel signal I_R of the red normal pixel **51***a* of the first pixel group is combined with the pixel signal I_r of the red normal pixel **51***b*, which is adjacent to the red normal pixel **51***a*, of the second pixel group. In a like manner, the pixel signal I_G of the green normal pixel **51***a* of the first pixel group is combined with the pixel signal I_g of the green normal pixel **51***b*, which is adjacent to the green normal pixel **51***a*, of the second pixel group. The pixel signal I_B of the blue normal pixel **51***a* of the first pixel group is combined with the pixel signal I_b of the blue normal pixel **51***b*, which is adjacent to the blue normal pixel **51***a*, of the second pixel group. With regard to the phase difference pixels **52***a* and **52***b*, the pixel signal K_G of the phase difference pixel **52***a* of the first pixel group is combined with the pixel signal K_g of the phase difference pixel **52***b* of the second pixel group, in a manner similar to the normal pixels **51***a* and **51***b*.

FIG. **10** illustrates the first composite image data **72** generated by the first pixel combining process. In the first composite image data **72**, each of pixel signals M_R, M_G, and M_B is generated by combining the pixel signals of the normal pixels **51***a* and **51***b*. The pixel signal N_G is generated by combining the pixel signals K_G and K_g of the phase difference pixels **52***a* and **52***b*. Here, the pixel signal N_G is depicted in a rectangular shape to show that the pixel signal N_G is obtained by combining the pixel signals of the phase difference pixels **52***a* and **52***b*. Note that a subscript represents the color of the color filter.

As described above, in the first pixel combining process, the pixel signals of two pixels are combined with each other to generate a first combined pixel. The pixel signals of the normal pixels **51***a* and **51***b* are combined with the pixel signals of the normal pixels **51***b* and **51***a*, respectively. The pixel signals of the phase difference pixels **52***a* and **52***b* are combined with the pixel signals of the phase difference pixels **52***b* and **52***a*, respectively. Therefore the first combining process is a combining process for combining the pixel signals of the pixels of the same type (hereinafter referred to as the same pixel type combining process). Thereby a first combined pixel is generated for each color.

The first combined pixel of the first composite image data **72** is based on the first combined pixel signal that is obtained by combining the pixel signals of the two obliquely adjacent pixels, so that the pixels are arranged in a square matrix as illustrated in FIG. **10**. Note that the pixels in the normal image data **71** are arranged in a honeycomb array, which corresponds to the pixel arrangement in the color image sensor **26**.

In the pixel combining mode, the second pixel combiner **46***b* performs the second pixel combining process to generate second composite image data **73** (see FIG. **11**) from the first composite image data **72**. In the second pixel combining process, the pixel signals of first combined pixels of the same color, which are closest in the Y direction (column direction) of the first composite image data **72** are added or averaged to generate a second combined pixel that is based on the added pixel signals or the average of the pixel signals. In other words, in the first composite image data **72**, the color of a given first combined pixel which corresponds to a first combined pixel signal differs from the color of another first combined pixel, which corresponds to another first combined pixel signal, adjacent to the given first combined pixel in the Y direction (above or below the given first combined pixel). Therefore the first combined pixel of a different color is skipped, and the pixel signals of the first combined pixels of the same color and which are closest in the Y direction are combined as illustrated in dotted lines in FIG. **10** to generate the second combined pixel.

To be more specific, in a column in which the pixel signal N_G derived from the phase difference pixels is absent, the red pixel signal M_R derived from the normal pixel is combined with another red pixel signal M_R which is derived from another normal pixel (the same pixel type combining process). This applies the same to the green and blue pixel signals M_G and M_B. In the column in which the pixel signal N_G derived from the phase difference pixels is present, the pixel signals are combined with each other in a like manner. In the column in which the pixel signal N_G derived from the phase difference pixels is present, the red pixel signal M_R is combined with the pixel signal M_R. However, the pixel signal N_G is combined with the pixel signal M_G. The pixel combining process for combining the red pixel signals M_R with each other is the same pixel type combining process. The pixel combining process for combining the pixel signal N_G with the pixel signal M_G is the different pixel type combining process because it involves each pixel signal of the normal pixels **51***a* and **51***b* and the phase difference pixels **52***a* and **52***b*.

FIG. **11** illustrates an arrangement of the pixels in the second composite image data **73**. Each of the pixel signals P_R, P_G, and P_B of the second combined pixels is generated by the same pixel type combining process in which the pixel signals of only the normal pixels **51***a* and **51***b* are combined with each other. The pixel signal Q_G is generated by the different pixel type combining process in which the pixel signals of the normal pixels **51***a* and **51***b* are combined with the phase difference pixels **52***a* and **52***b*. The second combined pixel in which the pixel signals of the phase difference pixels **52***a* and **52***b* are combined is depicted in an octagonal shape.

As illustrated in FIG. **12**, the pixel signal processor **32** comprises a pixel signal correction processor (corrector) **81**, a demosaicing processor **82**, a gamma correction processor **83**, an RGB/YCrCb conversion processor **84**, and the like.

The demosaicing processor **82** performs an interpolation process (demosaicing process) on the RAW data with the pixel signals of the phase difference pixels **52***a* and **52***b* and the pixel signal of a defective combined pixel **91** (see FIG. **14**) corrected by the pixel signal correction processor **81** so that one pixel has the pixel signals of three colors. Through the demosaicing process, the RAW data in which one pixel has the pixel signal of one color corresponding to the color of the color filter is converted into the image data in which each pixel has red, green, and blue pixel signals. Note that in the case where the demosaicing processor **82** performs the demosaicing process on the normal image data **71**, the demosaicing processor **82** also performs data interpolation to change the arrangement of the pixels from the honeycomb array to a square matrix.

The gamma correction processor **83** performs a gamma correction process based on a given gamma table. After the gamma correction process, the RGB/YCrCb conversion processor **84** performs YCbCr conversion on the composite image data and the normal image data.

The pixel signal correction processor **81** comprises a first calculator **86**, a second calculator **87**, an edge detector **88**, and a correction method selector **89**. The image sensor **26** outputs the RAW data in accordance with the imaging mode. As described above, in the normal mode, the RAW data is the normal image data **71**. In the wide dynamic range mode, the RAW data is the first composite image data **72**. In the pixel combining mode, the RAW data is the second composite image data **73**. The pixel signal correction processor **81** corrects the pixel signals K_G and K_g of the defective pixels that correspond to the phase difference pixels **52***a* and **52***b* and/or the pixel signals N_G and Q_G of the defective combined pixels in the RAW data of each type.

The first calculator **86** corrects the pixel signals K_G and K_g of the defective pixels and the pixel signal N_G and Q_G of the defective combined pixels through gain correction to generate the pixel signals with the corrected gains. For example, in the case where the pixel signal Q_G of the defective combined pixel of the second composite image data **73** is to be corrected, the pixel signal of the defective combined pixel is multiplied by a gain, which is based on the ratio between the pixel signal P_G of the normal combined pixel and the pixel signal Q_G of the defective combined pixel. Thereby the pixel signal with the corrected gain is generated.

For example, as illustrated in FIG. **13**, the image capture section **40** is divided into nine regions (A**1** to A**9**), and a gain to be multiplied is calculated for each region. For example, in the case where the pixel signal Q_G of the defective combined pixel in the second composite image data **73** is to be corrected, the first calculator **86** calculates an average value (hereinafter referred to as the first average value) of the pixel signals P_G of the normal combined pixels and an average value (hereinafter referred to as the second average value) of the pixel signals Q_G of the defective combined pixels for each of the regions A**1** to A**9**, and uses a ratio between the first average value and the second average value as a gain γ (γ=the first average value/the second average value) for each of the regions A**1** to A**9**. For this reason, the gain γ used by the first calculator **86** varies depending on the regions A**1** to A**9** and the subject.

Note that the gain correction for the pixel signal N_G of the defective combined pixel in the first composite image data **72** and the gain correction for the pixel signals K_G and K_g of the defective pixels (pixels which correspond to the phase difference pixels **52***a* and **52***b*) in the normal image data **71** are performed in the same manner as the gain correction for the second composite image data **73**.

The second calculator **87** corrects the pixel signals K_G and K_g of the defective pixels and the pixel signals N_G and Q_G of the defective combined pixels through interpolation. Thereby the interpolation-corrected pixel signal which has been subjected to the interpolation correction is generated. For example, as illustrated in FIG. **14**, in the case where the pixel signal Q_G of the defective combined pixel **91** of the second composite image data **73** is corrected through the interpolation, the second calculator **87** uses the green pixels which are disposed around the defective combined pixel **91** to generate the interpolation-corrected (or interpolated) pixel signal, which has been corrected through the interpolation correction. The pixels disposed around the defective combined pixel **91** are, for example, the normal combined pixels of the same color disposed above and below (in the Y direction or the column direction), left and right (in the X direction or the row direction), and in oblique directions (each direction where Y=±X), adjacent or closest to the defective combined pixel **91**.

To be more specific, each of the pixel signals P_G of normal combined pixel **92***a* and **92***e*, which are closest to the defective combined pixel **91** in the left-right direction, the pixel signals P_G of normal combined pixels **92***b* and **92***f* adjacent in a right oblique direction with respect to the defective combined pixel **91**, and the pixel signals P_G of normal combined pixels **92***d* and **92***h* adjacent in a left oblique direction with respect to the defective combined pixel **91** is used. In this embodiment, in the second composite image data **73**, the pixels closest to the defective combined pixel **91** in the up-down direction are defective combined pixels **92***c* and **92***g*. The result of the correction cannot be obtained properly in the case where the pixel signals of the defective combined pixels are used for correcting the pixel signals of the defective combined pixel **91**. Therefore each of such pixel signals Q_G is not used.

A method for generating the interpolation-corrected pixel signal by the second calculator **87** with the use of the normal combined pixel differs depending on the result of the edge detection performed by the edge detector **88**. In the case where the edge detector **88** detects an edge (of a subject) which is vertical (including substantially vertical) to a combining direction (Y direction, see FIG. **10**) of the second pixel combining process and located at round the defective combined pixel **91** to be corrected, the second calculator **87** uses the average value of the pixel signals of the normal combined pixels **92***a* and **92***e*, which are closest to the defective combined pixel **91** to be corrected in the left-right direction along the direction of the detected edge, as the interpolation-corrected pixel signal. In the case where the edge of the subject which is vertical to the combining direction of the second pixel combining process is not detected at around the defective combined pixel **91**, the average value of the pixel signals P_G of the surrounding normal combined pixels **92***a*, **92***d* to **92***f*, and **92***h* is used as the interpolation-corrected pixel signal.

The pixel signal N_G of the defective combined pixel in the first composite image data **72** and the pixel signal K_G of the defective pixel in the normal image data **71** are detected in a like manner. In this embodiment, however, the edge detector **88** does not detect the edge in the case of the first composite image data **72** and the normal image data **71**. The second calculator **87** uses the average value of the pixel signals of the green normal combined pixels or of the pixels which correspond to the normal pixels **51***a* and **51***b*, which are adjacent in up-down, left-right, or oblique directions to the defective combined pixel having the pixel signal N_G or the pixel signals K_G, as the interpolation-corrected pixel signal. In the case of the first composite image data **72** or the normal image data **71**, the green pixels which are closest to the pixel which corresponds to the defective combined pixel or the defective pixel in the up-down direction are the normal pixels which are generated from the pixel signals of the normal pixels **51***a* and **51***b*. Therefore these pixel signals of the normal pixels are used for calculating the interpolation-corrected pixel signal.

The edge detector **88** is activated in the pixel combining mode, and detects whether there is an edge (of the subject), which is substantially vertical to the combining direction of the second pixel combining process, at or around the defective combined pixel **91** to be corrected. In order to detect the edge, the pixel signals P_G and Q_G of the nine green pixels (the normal combined pixel and the defective combined pixels **92***a* to **92***h*) disposed around the defective combined pixel **91** are used (see FIG. **14**).

In order to detect the edge, first, the edge detector **88** calculates differences δ_{Y1} to δ_{Y3} between the pixel signals P_G and/or Q_G of the normal and defective combined pixels (out of **92***a* to **92***h*) in the Y direction parallel to the combining direction in the second pixel combining process, and then calculates a total sum (hereinafter referred to as the first edge amount) Δ_Y thereof. In the case where each pixel signal of the normal and defective combined pixels **92***a* to **92***h* is denoted by Pa, Pb, Qc, Pd to Pf, Qg, and Ph for the sake of distinction, the following is satisfied: $\delta_{Y1}=|Qc-Qg|$, $\delta_{Y2}=|Pb-Ph|$, $\delta_{Y3}=|Pd-Pf|$, $\Delta_Y=\delta_{Y1}+\delta_{Y2}+\delta_{Y3}$.

In a like manner, differences δ_{X1} to δ_{X3} between the pixel signals P_G and/or Q_G of the normal and defective combined pixels (out of **92***a* to **92***h*) are calculated in the X direction vertical to the combining direction in the second pixel combining process, and then a total sum (hereinafter referred to as the second edge amount) Δ_X thereof is calculated. The following is satisfied: $\delta_{X1}=|Pa-Pe|$, $\delta_{X2}=|Pb-Pd|$, $\delta_{X3}=|Ph-Pf|$, and $\Delta_X=\delta_{X1}+\delta_{X2}+\delta_{X3}$.

Furthermore, the edge detector **88** calculates a difference $D=\Delta_Y-\Delta_X$ between the first and second edge amounts Δ_Y and Δ_X, and compares the difference with a given threshold value (in this embodiment, "0"). As is obvious from the above-described calculations, the first and second edge amounts Δ_Y and Δ_X represent the intensities (magnitude) of the changes in the subject in the first and second directions, respectively. The difference D represents which of the changes in the first and second directions in the subject is greater than the other.

For example, in the case where the subject is substantially uniform and has little change at around the defective combined pixel **91** to be corrected, each of the first and second edge amounts Δ_Y and Δ_X is substantially "0". Naturally the difference D is also substantially "0". In the case where the subject has horizontal stripes, so that a change in the Y direction is large and an edge is present in the X direction, the amount of the first edge amount Δ_Y is large and the second edge amount Δ_X is substantially "0". Therefore in the case where approximately D>0 (in particular D>>0), the edge (of the subject) extending in the X direction is detected at or around the defective combined pixel **91** to be detected.

In the case where the subject has vertical stripes and a change is significant in the X direction and an edge extending in the Y direction is present, the first edge amount Δ_Y is substantially "0" and the second edge amount Δ_X is large. In the case of approximately $D<0$ (in particular $D<<0$), an edge (of the subject) extending in the Y direction is detected at or around the defective combined pixel **91** is to be corrected. The edge detector **88** detects the presence or absence and the direction of the edge based on the difference D between the first and second edge amounts Δ_Y and Δ_X. Thus, the comparison between a given threshold value and the difference D between the first and second edge amounts Δ_Y and Δ_X represents the detection of the direction (first direction) in which the difference D between the pixel signals is at the maximum and the detection of the edge vertical to the first direction. Note that in this embodiment, the threshold value is "0", but it may have an arbitrary value.

The edge detector **88** inputs the result of the comparison between the given threshold value and the difference D, between the first and second edge amounts Δ_Y and Δ_X, to the correction method selector **89**. Based on the result of the comparison, the correction method selector **89** selects one of the gain correction and the interpolation correction. In the case where the gain correction is selected, the gain-corrected pixel signal, which is generated by the first calculator **86**, replaces the pixel signal K_G or K_g of the defective pixel or the pixel signal N_G or Q_G of the defective combined pixel. In the case where the interpolation correction is selected, the interpolation-corrected pixel signal, which is generated by the second calculator **87**, replaces the pixel signal K_G or K_g of the defective pixel or the pixel signal N_G or Q_G of the defective combined pixel.

In order to select the method for correcting the pixel signal Q_G of the defective combined pixel **91** in the second composite image data **73**, for example, the correction method selector **89** selects the method for correcting the pixel signal of the defective combined pixel **91**, based on the result of the comparison between the given threshold value and the difference D, between the first and second edge amounts Δ_Y and Δ_X, inputted from the edge detector **88**. To be more specific, the correction method selector **89** always selects the interpolation-corrected pixel signal at least in the case of $D>0$. The interpolation-corrected pixel signal selected in this example is the average value of the pixel signals Pa and Pe of the normal combined pixels **92***a* and **92***e*, which are closest in the left-right direction to the defective combined pixel **91** to be corrected.

In the case where the correction method selector **89** selects the method for correcting the defective combined pixel (the pixel signal N_G) of the first composite image data **72** and the method for correcting the pixel signal of the defective pixel of the normal image data **71**, the correction method selector **89** detects, for example, the fineness and the contrast of the image of the subject in proximity of the defective combined pixel and the defective pixel (the pixels which correspond to the phase difference pixels **52***a* and **52***b*) to be corrected, and selects one of the gain-corrected pixel signal and the interpolation-corrected pixel signal so as to make the trace of the correction less conspicuous. Note that the interpolation-corrected pixel signal in this example is calculated using the pixel signals of all of the normal pixels or the normal combined pixels adjacent (or closest in each direction) in the up-down, the left-right, and the oblique directions to the defective pixel or the defective combined pixel.

Hereinafter, referring to FIG. **15**, an operation of the digital camera **11** is described. First, the power of the digital camera **11** is turned on to be ready for imaging. In response to this, the color image sensor **26** sequentially outputs the normal image data **71**, being the RAW data. The normal image data **71** is subjected to various processes such as the correction process of the pixel signals K_G and K_g of the phase difference pixels **52***a* and **52***b* and the demosaicing process, and then displayed as a live view image on the display section **16** (S**10**) in a manner similar to the normal mode.

Upon pressing of the release button **19** and turning on of the S**1** switch (S**11**), the AE and AF control is performed (S**12**). The AE controller (not shown) takes out the pixel signals of the normal pixels **51***a* and **51***b* from the normal image data and calculates the exposure value. The aperture stop value and the shutter speed are calculated based on the exposure value. In order to perform the AF control, the AF detector **31** obtains the pixel signals K_G and K_g of the phase difference pixels **52***a* and **52***b* from the normal image data **71** and calculates the focus evaluation value based on the obtained pixel signals. Based on the focus evaluation value, the focusing lens is moved to the focusing position.

Upon further pressing of the release button **19** and turning on of the S**2** switch (S**13**), the imaging is performed with the previously determined exposure conditions (S**14**). Upon imaging, the color image sensor **26** outputs the RAW data which corresponds to the imaging mode chosen previously. First, the pixel signal correction processor **81** performs the correction process on the pixel signals of the phase difference pixels **52***a* and **52***b* or the pixel signal of the defective combined pixel contained in the RAW data outputted from the color image sensor **26**. Thereafter, the RAW data is sequentially subjected to the demosaicing process, the gamma correction process, the RGB/YCrCb conversion process, and the like, and then stored in the memory **36**.

For example, in the case where the normal mode is chosen (NO in S**15**), the normal image data **71** (see FIG. **9**) is outputted as the RAW data. The normal image data **71** is generated by reading a pixel signal from each pixel in the color image sensor **26**. Since the pixel combining process is not performed, each pixel of the normal image data **71** corresponds to each pixel of the image sensor **26**. In the color image sensor **26**, all of the green pixels, of the first pixel group, which are closest to the phase difference pixel **52***a* of the first pixel group in the up-down, the left-right, and the oblique directions are normal pixels **51***a*, and there are eight of them at the maximum. All of the green pixels, of the second pixel group, which are closest to the phase difference pixel **52***b* of the second pixel group in the up-down, the left-right, and the oblique directions are also the normal pixels **51***b*, and there are eight of them at the maximum. The pixel signal of the defective pixel which corresponds to the phase difference pixel **52***a* or **52***b* of the normal image data **71** is corrected properly by either of the gain correction and the interpolation correction, with the use of the pixel signals of the eight closest normal pixels **51***a* or **51***b* at the maximum. The correction method selector **89** may select one of the gain correction and the interpolation correction with less trace of the correction. Thereby the pixel signal of the defective pixel which is based on the phase difference pixel **52***a* or **52***b* is corrected accurately (S**16**).

In the case where the wide dynamic range mode is chosen (NO in S**15**), the first pixel combiner **46***a* combines the pixel signals of two obliquely adjacent pixels of the first and second pixel groups in the normal image data **71**. Thereby the first composite image data **72** is obtained. The color image sensor **26** outputs the first composite image data **72** as the RAW data. In the first composite image data **72**, each of the first combined pixel signals of the pixels closest to the defective combined pixel (the pixel signal N_G), in which the pixel signals of the phase difference pixels **52**a and **52**b are combined with each other, in the up-down, the left-right, and the oblique directions is the pixel signal M_G, and the defective combined pixel (the pixel signal N_G) does not exist. For this reason, either of the gain correction and the interpolation correction is performed properly. The correction method selector **89** selects one of the gain correction and the interpolation correction which allows less trace of correction and corrects the pixel signal of the defective combined pixel through the selected correction method (S**16**).

In the case where the pixel combining mode is chosen (YES in S**15**), the color image sensor **26** sequentially performs the first pixel combining process with the first pixel combiner **46**a and the second pixel combining process with the second pixel combiner **46**b, and thereby outputs the second composite image data **73** as the RAW data (S**17**). The pixel signal Q_G of the defective combined pixel contained in the second composite image data **73** is the pixel in which the pixel signals I_G and I_g from the normal pixels **51**a and **51**b are combined with the pixel signals K_G and K_g from the phase difference pixels **52**a and **52**b through the first and second pixel combining processes. Therefore, in the case where the edge of the subject is present in the close proximity, the correction may not be performed properly through the gain correction or the interpolation correction in a manner similar to that applied to the normal image data **71** or the first composite image data **72**.

In the case of imaging performed in the pixel combining mode, the edge detector **88** detects the presence or absence and the direction of the edge of the subject. The correction is performed in a manner different from those of the normal image data **71** and the first composite image data **72**, depending on the direction of the detected edge.

To be more specific, the edge detector **88** calculates the first edge amount Δ_Y which represents the presence or absence of the edge of the subject in the X direction (S**18**). The edge detector **88** calculates the second edge amount Δ_X which represents the presence or absence of the edge in the Y direction (S**19**). The difference D between the first edge amount Δ_Y and the second edge amount Δ_X is calculated. The difference D is compared with the given threshold value ("0") to detect the direction in which the edge amount is at the maximum. Thus, the edge is detected (S**20**). Note that S**18** to S**20** correspond to the edge detection step.

In the case where the difference D between the first and second edge amounts Δ_Y and Δ_X is greater than the given threshold value (0) (YES in S**20**), the edge (of the subject) extending in the first direction is present in the proximity of the defective combined pixel to be corrected. In the second composite image data **73**, the pixel signal Q_G of the defective combined pixel is generated by the second pixel combining process. In the second pixel combining process, the pixel signal N_G of the defective combined pixel is combined with the pixel signal M_G of the normal combined pixel, and the defective combined pixel and the normal combined pixel are close to each other in the Y direction. In the case where the edge of the subject is present in the X direction, it is regarded that the pixel signals are combined through the second pixel combining process which is performed across the edge.

The value of the pixel signal Q_G of the second combined pixel varies depending on whether the pixel combining process is performed across the edge of the subject or not, even if the pixel signal Q_G is obtained by combining the pixel signals N_G and M_G of the first combined pixel signals which are close to each other. In other words, in the case where the pixel signals of the pixels located across the edge of the subject are combined with each other, the pixel signal Q_G takes a special value.

The gain γ used for the normal gain correction is calculated based on the average sensitivity ratio between the pixel signal Q_G and the pixel signal P_G in each of the relatively wide regions A**1** to A**9** illustrated in FIG. **13**. Therefore it is suitable for the gain correction of the pixel signal Q_G generated by the pixel combining process which is not performed across the edge. However, it is not suitable for the correction of the special pixel signal Q_G that is generated by the pixel combining process performed across the edge.

In the case where the pixel signal Q_G is corrected by the normal interpolation and the number of the pixels (pixel signal P_G) is substantially greater on one of the sides than on the other side with respect to the edge of the subject, the value of the interpolation-corrected pixel signal becomes close to the value of the pixel signal P_G of the pixel located on the one side in which the number of the pixels (the pixel signals P_G) is greater than that of the other side. On the other hand, in the case where the number of the pixels (the pixel signal P_G) used for the interpolation is greater on the other side than that on the one side, the value of the interpolation-corrected pixel signal becomes closer to the value of the pixel signal P_G of the pixel located on the other side. For this reason, it is difficult to obtain an accurate and stable result through the normal interpolation correction.

In the case where the difference between the first and second edge amounts Δ_Y and Δ_X is greater than the given threshold value (0), in order to generate an interpolation-corrected pixel signal for correcting the pixel signal Q_G of the defective combined pixel in which the second pixel combining process has possibly been performed across the edge, the second calculator **87** generates the interpolation-corrected pixel signal for the defective combined pixel with the use of only the pixel signals P_G located in a direction (X direction) along the edge. Then the correction method selector **89** replaces the pixel signal Q_G of the defective combined pixel with the interpolation-corrected pixel signal that is generated using only the pixel signals P_G of the pixels located along the edge (S**20**). In other words, the pixel signal Q_G of the defective combined pixel in which the pixel combining process has possibly been performed across the edge of the subject is corrected through the interpolation using only the pixel signals P_G of the normal combined pixels in which the pixel combining process has possibly been performed across the edge of the subject and which are located close to the defective combined pixel. Note that the correction step refers to generating the interpolation-corrected pixel signal and replacing the pixel signal Q_G.

The pixel signal Q_G of the defective combined pixel in which the pixel combining process has possibly been performed across the edge of the subject is, for example, the pixel signal of the pixel located over the edge of the subject. The pixel with the target correction value is also located over the edge of the subject and close to the defective combined pixel. In other words, the target correction value is the pixel signal of the normal combined pixel which does not require correction. For this reason, the correction is performed accurately by correcting the pixel signal through the interpolation along the edge as described above.

Note that in the case where the difference D between the first and second edge amounts Δ_Y and Δ_X is less than or equal to a given threshold value "0" (NO in S**19**), the edge extending in the X direction is not present in the proximity of the defective combined pixel. Therefore the pixel signal Q_G is corrected properly by the normal gain correction or the normal interpolation correction (S**16**).

An operation of the above correction is described with the use of a more specific example. As illustrated in FIG. **16**, in the normal image data **71**, an edge **101**, which extends in the X direction, is located immediately below the defective pixels (the pixel signals K_G and K_g). A subject having a region (hereinafter referred to as the dark region) **102**, which is located above the edge **101** (upstream in the Y direction), and a region (hereinafter referred to as the bright region) **103**, which is located below the edge **101** (downstream in the Y direction), is imaged. The sensitivity of each of the phase difference pixels **52***a* and **52***b* is half (½) the sensitivity of each of the normal pixels **51***a* and **51***b*. The value of each of the pixel signals I_G and I_g in the dark region **102** is "50". The value of each of the pixel signals K_G and K_g in the dark region **102** is "25". The value of each of the pixel signals I_G and I_g in the bright region **103** is "200". The value of each of the pixel signals K_G and K_g in the bright region **103** is "100".

The first pixel combining process is performed on the normal image data **71** to generate the first composite image data **72**. As illustrated in FIG. **17**, the edge **101** of the subject is located immediately below the defective combined pixel (the pixel signal N_G) and parallel in the X direction. In the dark region **102**, the value of the pixel signal M_G is "100 (=50+50)". The value of the pixel signal N_G is "50 (=25+25)". In the bright region **103**, the value of the pixel signal M_G is "400 (=200+200)". The value of the pixel signal N_G (not shown) is "200 (=100+100)". In FIG. **17**, the combined pixels which are connected by dotted lines are to be combined with each other in the second pixel combining process.

The second pixel combining process is performed on the first composite image data **71** to generate the second composite image data **73**. Thereby, as illustrated in FIG. **18**, the edge **101** of the subject is changed to a row (hereinafter referred to as the edge) **104** of the pixel signals which have been combined across the edge **101** through the second pixel combining process. A dark region **106** is located above the edge **104**. A bright region **107** is located below the edge **104**. In the case where the pixel signal of the second combined pixel, which is generated by the second pixel combining process, is calculated by averaging the two pixel signals, the value of the pixel signal P_G is "100 (=(100+100)/2)" and the value of the pixel signal Q_G is "75 (=(50+100)/2)" in the dark region **106**. The value of the pixel signal P_G is "400 (=(400+400)/2)" and the value of the pixel signal Q_G is "300 (=(200+400)/2)" in the bright region **107**. Furthermore, the value of the pixel signal P_G is "250 (=(100+400)/2)" and the value of the pixel signal Q_G is "225 (=(50+400)/2)", which are located over the edge **104**.

A case in which a defective combined pixel **111** (pixel signal Q_G=225) located over the edge **104** in the middle of FIG. **18** is corrected by various methods is considered. First, in the case where the normal gain correction is performed, the ratio between the pixel signal P_G and the pixel signal Q_G in the dark region **106** is 4:3, and the ratio between the pixel signal P_G and the pixel signal Q_G in the bright region **107** is also 4:3. Accordingly, the gain γ calculated by the first calculator **86** is 4/3. The value of the gain-corrected pixel signal obtained by multiplying the pixel signal Q_G of the defective combined pixel **111** by the gain γ is "300 (=225×4/3)".

However, the target correction value (the value corrected most accurately) of the pixel signal Q_G of the defective combined pixel **111** is the same as the pixel value of a normal combined pixel **112***a* or **112***e* located over the edge **140**, that is, "250". For this reason, after the gain correction, the defective combined pixel **111** becomes brighter than the adjacent pixels located over the edge **104**. As a result, the trace of the correction is conspicuous.

In the case where the edge detector **88** detects the edge **104** with the use of the eight pixels **112***a* to **112***h*, which are located around the defective combined pixel **111**, the first edge amount Δ_X=0 because δ_{X1}=|250−250|=0, δ_{X2}=|100−100|=0, and δ_{X3}=|400 −400|=0. The second edge amount is Δ_Y=825 because δ_{Y1}=|75−300|=225, δ_{Y2}=|100−400|=300, and δ_{Y3}=|100−400|=300. The difference D between the first and second edge amounts Δ_Y and Δ_X is D=825−0=825>0. Therefore it is detected that the defective combined pixel **111** is located over the edge **104** that extends in the X direction.

The second calculator **87** determines the average value "250" of the pixel signals P_G of the normal combined pixels **112***a* and **112***e*, which are closest to the defective combined pixel **111** in the left-right direction (X direction), to be the interpolation-corrected pixel signal. The correction method selector **89** replaces the pixel signal Q_G of the defective combined pixel **111** with the interpolation-corrected pixel signal "250". Thereby the pixel signal Q_G of the defective combined pixel **111** agrees with the target correction value and is corrected accurately.

Note that in the case where the pixel signal of the interpolation-corrected pixel signal is calculated using the pixel signal P_G of each of the normal combined pixels **112***a* and **112***e* located on the left and the right of the defective combined pixel **111** and the pixel signal P_G of each of the normal combined pixels **112***b*, **112***d*, **112***f*, and **112***h* located in the oblique directions in the proximity of the defective combined pixel **111**, the value of the pixel signal is "250 (100+100+250+250+400+400)/6)". It seems as if the pixel signal Q_G of the defective combined pixel **111** can be corrected by the normal interpolation correction. However, with regard to an actual subject, an error may be increased because the pixel signal P_G of each of the pixels **112***b* and **112***d* in the dark region **106** and the normal combined pixels **112***f* and **112***h* in the bright region **107** is used for calculating the interpolation-corrected pixel signal. In the above-described interpolation correction performed along the edge **104**, which extends in the first direction, the pixel signal of the defective combined pixel **111** located above the edge **104** is corrected in consideration of only the pixels located on the edge **104**. As a result, the error is inhibited and more accurate correction is possible even in the case of the actual subject.

In the above embodiment, the pixel signal of the defective combined pixel of the second composite image data **73** is corrected by the conventional method (S**16**) in the case where the difference D between the first and second edge amounts Δ_Y and Δ_X is less than or equal to the given threshold value. However, in the case where the difference D between the first and second edge amounts Δ_Y and Δ_X is less than or equal to the threshold value and the condition (|Ca−Cg|>C_{TH}) described in S**27** of FIG. **19** is satisfied, it is preferred to correct the pixel signal of the defective combined pixel by the gain correction.

As illustrated in FIG. **19**, in the case where the difference D between the first and second edge amounts Δ_Y and Δ_X is less than or equal to the given threshold value (for example "0") (NO in S**20**), the magnitude of the difference |Ca−Cg| between the gain-corrected pixel signal Cg, which is calculated by the first calculator **86**, and the interpolation-corrected pixel signal Ca, which is calculated by the second calculator **87**, is calculated, and compared with the threshold value C_{TH} (S**27**). In the case where the difference |Ca−Cg| between the gain-corrected pixel signal Cg and the interpolation-corrected pixel signal Ca is greater than the threshold value C_{TH} (YES in S**27**), the pixel signal of the defective combined pixel is replaced with the gain-corrected pixel signal (S**28**).

As described above, in the case where the difference D between the first and second edge amounts Δ_Y and Δ_X is less than or equal to the threshold value, the gain-corrected pixel signal Cg is compared with the interpolation-corrected pixel signal Ca. In the case where the difference between the gain-corrected pixel signal Cg and the interpolation-corrected pixel signal Ca is large, the gain-corrected pixel signal Cg is used with higher priority. Thereby, the result of the correction is excellent in the case where a subject with thin vertical stripes is imaged.

As illustrated in FIG. **20**, in the normal image data **71** obtained by imaging a subject with vertical stripes of a relatively short period, it is assumed that there are edges **121**A and **121**B, dark regions **123**A and **123**B, and a bright region **124**. Suppose the sensitivity of each of the phase difference pixels **52***a* and **52***b* is half (½) the sensitivity of each of the normal pixels **51***a* and **51***b*. The value of the pixel signal I_G or I_g in the dark region **123**A or **123**B is "50". The value of the pixel signal K_G or K_g in the dark region **123**A or **123**B is "25". The value of the pixel signal I_G or I_g in the bright region **124** is "200". The value of the pixel signal K_G or K_g in the bright region **124** is "100".

In this case, as illustrated in FIG. **21**, in the first composite image data **72**, the value of the pixel signal M_G is "100" and the value of the pixel signal N_G is "50" (not shown) in the dark region **123**A or **123**B. The value of the pixel signal M_G is "400" and the value of the pixel signal N_G is "300" in the bright region **124**. The pixel signals of the pixels connected by the dotted lines are those combined in the second pixel combining process, so that the pixel signals are not added across the edge **121**A or **121**B in the second pixel combining process. As illustrated in FIG. **22**, in the second composite image data **73**, the value of the pixel signal P_G is "100" and the value of the pixel signal Q_G is "75" (not shown) in the dark region **123**A or **123**B. The value of the pixel signal P_G is "400" and the value of the pixel signal Q_G is "300" in the bright region **124**.

Next, a case in which the pixel signal Q_G of defective combined pixel **131**, which is located at the center in FIG. **22**, is described. The value of the first edge amount Δ_X is "300" and the value of the second edge amount £ is "0", so that the difference D between the first and second edge amounts Δ_X and Δ_Y takes a negative value (D=−300<0). In this case, the first calculator **86** and the second calculator **87** calculate the gain-corrected pixel signal Cg and the interpolation-corrected pixel signal Ca, respectively.

First, with regard to the gain-corrected pixel signal Cg, the gain γ is 4/3 because the ratio between the pixel signal P_G and the pixel signal Q_G is 4:3 irrespective of the dark region **123**A or **123**B or the bright region **124**A. Accordingly, the gain-corrected pixel signal Cg of the defective combined pixel **131** is "400". The interpolation-corrected pixel signal Ca is calculated based on the average value of the pixel signals P_G of the normal combined pixels **132***a*, **132***b*, **132***d* to **132***f*, and **132***h* out of the combined pixels **132***a* to **132***h*, which are located around the defective combined pixel **131**. For this reason, the value of the interpolation-corrected pixel signal Ca is "200".

The value of gain-corrected pixel signal Cg is twice the value of the interpolation-corrected pixel signal Ca, and the difference between them is "200". The target correction value of the pixel signal Q_G of the defective combined pixel **131** in the bright region **124**A is "400", which is the same as the pixel signal P_G of the normal combined pixel in the bright region **124**A. Therefore the gain correction allows accurate correction in the case where the subject with thin vertical stripes is imaged. In other words, the gain correction is set to be performed in the case where the difference between the gain-corrected pixel signal Cg and the interpolation-corrected pixel signal Ca is large, and thereby the result of the correction is excellent even if the subject with thin vertical stripes is imaged.

In the above embodiment, the color image sensor **26** is provided with the pixel combining circuit **46**. In the case where imaging is performed in the pixel combining mode, the RAW image data in which the pixel signals are combined is outputted from the color image sensor **26**. Instead, the pixel combining circuit **46** may be provided external to the color image sensor **26**. For example, the pixel combining circuit **46** may be provided in the pixel signal processor **32**. In this case, the color image sensor **26** always outputs the normal image data **71**. The pixel signal processor **32** combines the pixel signals and corrects the pixel signals of the defective pixels and the defective combined pixels.

The pixel signal correction processor **81** is provided in the pixel signal processor **32**, but the pixel signal correction processor **81** may be provided in the color image sensor **26**. In this case, the color image sensor **26** may combine the pixel signals, and then the image data in which the pixel signals of the defective pixel and the defective combined pixel are corrected may be outputted as the RAW data in the case where the imaging is performed in the pixel combining mode.

The normal image data **71** or the first composite image data **72** may be used to detect the edge of the subject. In order to detect the edge based on the normal image data **71** or the first composite image data **72**, a difference between the pixel signals in the X direction and a difference between the pixel signals in the Y direction are calculated and then compared with each other. Thereby the presence of the edge, which extends in the vertical direction with respect to the direction in which the difference between the pixel signals is at a maximum, is detected.

The edge detector **88** calculates the edge amounts Δ_X and Δ_Y in the two directions: the X direction and the Y direction. In addition, the edge detector **88** may calculate an edge amount in another direction such as an oblique direction. In other words, a direction in which the edge amount is calculated is arbitrary as long as the edge which is vertical to the direction of adding the pixel signals is detected in the second pixel combining process. In the case where the edge amounts are calculated in three or more directions, a method for calculating the edge amount in each direction is based on the above embodiment. In the case where the edge amounts are calculated in three or more directions, the edge amounts are compared with each other and a direction with the largest edge amount is detected. Thereby the presence of the edge which is vertical to the direction with the largest edge amount is detected.

In the case where imaging is performed in the pixel combining mode, the second composite image data **73**, in which four pixel signals in total are combined with each other, is generated. The number of the pixel signals to be combined may be arbitrary. For example, the present invention is suitable for the case where two pixel signals are combined with each other as long as the pixel signal of the normal pixel is combined with the pixel signal of the phase difference pixel. Composite image data in which three or more pixel signals are combined with each other may be generated.

In the case where the defective pixel and the defective combined pixel are corrected through the interpolation, the average value of the pixel signals of the several pixels around the defective pixel or the like to be corrected is used as the interpolation-corrected pixel signal, but the specific methods for interpolation are arbitrary. For example, the interpolation-corrected pixel signal may be generated by polynomial or spline interpolation.

The pixels and the color filters in the color image sensor **26** are arranged in the so-called honeycomb EXR array, but the arrangements of the pixel and the color filters in the color image sensor are arbitrary as long as the composite image data is generated through the different pixel type combining process. For example, the present invention is suitable for the case where the phase difference pixels are provided in an image sensor of Bayer arrangement as long as the same pixel type combining process and the different pixel type combining process are performed to generate the composite image data.

The pixel signals of the obliquely adjacent pixels of the first pixel group and the second pixel group are combined with each other and then the two pixel signals of the same color in the Y direction are combined with each other by way of example. The combination of the pixel signals and the order of combining the pixel signals may be changed arbitrarily.

The pixel signals are added in the first pixel combining process and the pixel signals are averaged in the second pixel combining process, by way of example. To perform the pixel combining process through adding or averaging is determined arbitrarily. For example, the first pixel combining process may be performed through averaging the pixel signals. The second pixel combining process may be performed through adding the pixel signals.

Every fourth pixel in the X and Y directions in each of the first and second pixel group is the phase difference pixel **52***a* or **52***b*, but the arrangements of the phase difference pixels **52***a* and **52***b* in the image capture section **40** are arbitrary. The phase difference pixel **52***a* of the first pixel group is disposed next to the phase difference pixel **52***b* of the second pixel group by way of example. These pixels may not be disposed next to each other.

The color image sensor has three types of pixels, the B, G, and R pixels of three primary colors of the additive color system. Furthermore, a pixel of a special color, for example, skin color or the like may be added to use four or more types of pixels. Instead of the pixels of the three primary colors of the additive color system, the pixels of three primary colors of the subtractive color system, Y, M, and C may be used. The normal pixels of each color are provided but there is only one type of phase difference pixels, which correspond to the color G. However, there may be two or more types of phase difference pixels. For example, the phase difference pixels of the colors G, B, and R may be provided.

Note that the present invention is applicable to digital cameras, video cameras, and portable electronic devices (mobile phones, PDAs, smartphones, notebook computers, and the like) with camera functions.

Various changes and modifications are possible in the present invention and may be understood to be within the present invention.

What is claimed is:

1. An image capture device comprising:

a color image sensor having a plurality of normal pixels and two or more phase difference pixels, the normal pixel isotropically receiving incident light, the phase difference pixel selectively receiving a part of the incident light;

a pixel combining unit for performing a same type combining process, in which first pixel signals from the normal pixels of the same color or second pixel signals from the phase difference pixels of the same color are combined to generate a first combined signal, and a different type combining process, in which the first pixel signal and at least one of the second pixel signals of the same color are combined to generate a second combined signal, to produce a composite image, the composite image being composed of a first combined pixel that is based on the first combined signal and a second combined pixel that is based on the second combined signal;

an edge detector for detecting an edge of a subject by detecting a first direction in which a difference between the first pixel signal and the second pixel signal of the same color or a difference between the first combined signal and the second combined signal of the same color is at a maximum, the edge being vertical to the first direction; and

a corrector for correcting the second combined signal of the second combined pixel through an interpolation process using the first combined signal of the first combined pixel in a case where the different type combining process is performed across the edge, the first combined pixel being disposed in a second direction which is along the edge and vertical to the first direction, the first combined pixel having the same color as the second combined pixel to be corrected.

2. The image capture device according to claim **1**, wherein there are at least three types of the normal pixels corresponding three primary colors, respectively, and there is at least one type of the phase difference pixels corresponding to one of the three primary colors.

3. The image capture device according to claim **2**, wherein the corrector calculates an average value of the first combined signals of the first combined pixels and replaces the second combined signal of the second combined pixel to be corrected, with the average value, and the first combined pixels are disposed in the second direction which is along the edge and vertical to the first direction and have the same color as the second combined pixel to be corrected.

4. The image capture device according to claim **2**, wherein the pixel combining unit generates the first combined signal through combining the four first pixel signals of the same color or the four second pixel signals of the same color in the same type combining process, and

generates the second combined signal through combining four of the first and second pixel signals including at least a pair of the first and second pixel signals in the different type combining process.

5. The image capture device according to claim **2**, wherein the pixel combining unit generates the first combined signal through combining the two first pixel signals of the same color or the two second pixel signals of the same color in the same type combining process, and

generates the second combined signal through combining the one first pixel signal with the one second pixel signal in the different type combining process.

6. The image capture device according to claim 1, wherein the edge detector calculates the difference in each of a specific direction extending between the normal pixel for generating the first pixel signal and the phase difference pixel for generating the second pixel signal and another direction vertical to the specific direction, and the first pixel signal and the second pixel signal are combined in the different type combining process.

7. The image capture device according to claim 6, wherein, in order to calculate the difference, the edge detector uses the first combined signals of the first combined pixels disposed opposite to each other with respect to the second combined pixel to be corrected.

8. The image capture device according to claim 1, wherein the color image sensor has a first pixel group, in which the plurality of pixels are arranged in a square matrix, and a second pixel group, in which the plurality of pixels are arranged in a square matrix at the same arrangement pitch as the first pixel group, and

the pixels in the second pixel group are disposed in positions obliquely shifted from positions of the pixels in the first pixel group, respectively, and

the first pixel group and the second pixel group are provided with color filters of the same color arrangement.

9. The image capture device according to claim 8, wherein the phase difference pixel of the first pixel group and the phase difference pixel of the second pixel group are of the same color and adjacent to each other in an oblique direction.

10. The image capture device according to claim 9, wherein every fourth pixel in row direction and column direction of each of the square matrices is the phase difference pixel, and the normal pixel of the same color and the same pixel group as the phase difference pixel is disposed between the phase difference pixels.

11. The pixel correction method comprising the steps of:

imaging a subject with a color image sensor having a plurality of normal pixels and two or more phase difference pixels, the normal pixel isotropically receiving incident light, the phase difference pixel selectively receiving a part of the incident light;

performing a same type combining process, in which first pixel signals from the normal pixels of the same color or second pixel signals from the phase difference pixels of the same color are combined to generate a first combined signal, and a different type combining process, in which the first pixel signal and at least one of the second pixel signals of the same color are combined to generate a second combined signal, to produce a composite image, the composite image being composed of a first combined pixel that is based on the first combined signal and a second combined pixel that is based on the second combined signal;

detecting an edge of the subject by detecting a first direction in which a difference between the first pixel signal and the second pixel signal of the same color or a difference between the first combined signal and the second combined signal of the same color is at a maximum, the edge being vertical to the first direction; and

correcting the second combined signal of the second combined pixel through an interpolation process using the first combined signal of the first combined pixel in a case where the different type combining process is performed across the edge, the first combined pixel being disposed in a second direction which is along the edge and vertical to the first direction, the first combined pixel having the same color as the second combined pixel to be corrected.

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